Essays on Technology Transfer, Energy Investment under Uncertainty, and Pro-Social Behavior.

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Environmental Policy has become an increasingly important topic over the last decades. Issues such as acid rain, ozone depletion and most recently climate change required global regulation in order to avoid serious damages to the environment. Whereas the acid rain and ozone depletion issues have been successfully dealt with (Barrett, 2003), the global community has not been able to address climate change on a global scale. The European Union has been spearheading global climate change efforts by implementing an Emissions Trading System for CO_2 emissions for most of its industrial and energy producers, but due to lacking global support efforts have been reduced. One important issue is how to integrate developing countries which do not have an emission limiting system in place with developed countries that do. A mechanism that has been set up to deal with this issue is the Clean Development Mechanism (CDM). Developed country companies can invest into projects operating in developing countries, and receive emission permits in their home market for the emission reduction their involvement brings about. This mechanism was supposed to increase abatement activity in developing countries, as well as decrease the cost of complying with permit markets in developed countries.

Chapter 2 of this thesis,"Technology Transfer Mechanisms and International Cooperation to Combat Climate Change", evaluates the effectiveness of the CDM and proposes an alternative mechanism to address a range of issues for which it has been criticized. Specifically, a new technology transfer mechanism is proposed, labeled Green Technology Banks, as part of a climate change agreement that includes emission limits for developed and developing countries. The mechanism is evaluated according to the following five criteria, standard in the literature that analyses technology-oriented agreements: environmental effectiveness, technological effectiveness, economic efficiency, incentives for participation and administrative feasibility. Under the assumption that several permit markets exist that are imperfectly linked, it is shown that the mechanism performs well according to the specified criteria, while the largest obstacle remains the acceptance of emission limits by developing countries. However, ancillary benefits, access to advanced technology and increased government revenue from emission trading represent a sizable compensation package. Developed countries would have to shoulder most of the cost, but considering the recent efforts to establish the Green Climate Fund as part of a new international climate change architecture, the willingness to pay for such efforts seems to be on the rise.

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Chapter 3

Another important issue concerning the CDM is its effect on investment into renewable energy in developed countries. Theoretically, it reduces the incentive to invest into renewable energy sources since it allows the usage of cheaper permits (Blanco and Rodrigues, 2008). This effect has not been studied quantitatively in an uncertain investment environment. Permit prices on the European emissions market are highly influenced by political process and have seen large drops and rises since its inception. Furthermore, energy investment is considered as irreversible. A methodology that is well suited to address such an issue is real-options theory.

In Chapter 3 of this thesis,"The Clean-Development Mechanism, Stochastic Permit Prices and Energy Investments", the impact on energy investments stemming from different emission permit classes is analyzed. Permits that are allocated inside the European Emission Trading Scheme and secondary Certified Emission Reductions permits (sCER) originating from the Clean Development Mechanism are considered. One price taking firm which is subject to emission regulation has the choice to invest into a gas or a wind power plant. The firm faces uncertainty regarding stochastically evolving permits prices, while it receives a premium on the electricity price for wind energy. As a first step, the value of the option to invest into a gas power plant over time is determined. Then, the investment probability of a gas power investment in a range of policy scenarios is calculated. Allowing the usage of sCER permits in the present policy framework has a positive impact on gas power investment. Decoupling the price processes has a similar effect. If the quota of sCER permits is doubled, the decrease in the investment probability for wind power is large. Finally, we ran sensitivity tests for different parameter values. We find that investment behavior changes significantly with differing interest rates, the wind energy premium and volatility rate.

The chapter is based on a cooperation with Prof. Philipp Hieronymi from the University of Illinois at Urbana-Champaign, Department of Mathematics.

Chapter 4

Lobbying activity from companies, NGOs, fossil energy and renewable energy producers have increased since the aforementioned environmental issues became a political priority. In Europe large lobbying organizations such as EUR-ELECTRIC representing large energy producers with high CO_2 levels, or the European Wind Energy Association with over 700 members from 60 countries have been formed. Whereas the latter organization is interested in achieving a more generous support mechanism for its members, such as feed-in tariffs, the former is more interested in reducing the burden environmental policy puts on its members. One example of reducing the burden is trying to increase the overall cap of the Emission Trading System, thereby lowering the price per permit. Considering the impact of lobbying from a real-options perspective in an uncertain environment with respect to permit prices has not been analyzed in the literature so far.

Chapter 4,"The Influence of Permit Price Uncertainty and Lobbying on Energy Investments", addresses the issue of how an investor chooses when facing the choice to replace a pre-determined generation capacity by investing into wind or gas power. If he chooses gas power, he has to obtain emission permits. The permit price develops according to a geometric Brownian Motion. Furthermore, the investor can fund lobbying efforts, rendering gas or wind power more profitable. We find that current permit prices are insufficient to induce renewable investment and wind power lobbying must be very effective in order to induce investment in this power type. Gas power lobbying is largely too costly due to the low permit price. In a United States-like situation with no permit market, no effective renewable support scheme, and very strong gas lobbying efforts, close to no renewable capacity will be installed. Depending on the scenario, the social cost of subsidizing wind energy can be large.

The chapter is again based on a cooperation with Prof. Philipp Hieronymi from the University of Illinois at Urbana-Champaign, Department of Mathematics.

Chapter 5 and 6

Whereas the previous chapters addressed the issues of technology transfer and energy investment under uncertainty, chapters 5 and 6 of this thesis consider pro-social behavior in the setting of the TV-Show *Come Dine with Me* from a theoretical and empirical point of view. In the show, five contestants prepare a dinner for each other during the course of a week and evaluate each other's performance. The winner receives a monetary prize. Evaluations remain concealed until the show is broadcast. Because actual voting behavior remains concealed during the show, a contestant could evaluate his/her opponents with zero in an effort to increase his own chances of winning without risking later punishment in the form of low scores. However, when looking at the actual data from the show, such behavior is virtually never observed. One potential explanation for this observation is that interaction between human beings is, to a large extent, governed by social norms that have evolved over time and have been instilled in us since childhood. In the absence of compliance to social norms, everyday interaction would be difficult because every situation would require the persons involved to establish acceptable behavior anew or to coordinate regarding some mutually acceptable behavior. Compliance with a social norm can be enforced through so-called moralistic punishment. Moralistic punishment is defined as: "... the enforcement of social norms by outraged but otherwise not directly affected third parties" (Carpenter and Matthews (2012), p. 555). Another important dimension that leads people to adhere to norms is the potential loss of reputation in the eyes of their peers, often termed social approval (Benabou and Tirole, 2003, 2006; Bernheim, 1994; Holländer, 1990). In his seminal article, Bernheim (1994) postulates: "When popularity is sufficiently important relative to intrinsic utility (defined as utility directly derived from consumption), many individuals conform to a single, homogenous standard of behavior, despite heterogeneous underlying preferences" (p. 844). Bernheim's model also allows for deviations from a norm for agents with extreme preferences. This explains the need for third party punishment, because in certain situations the intrinsic utility gain may lead to deviations from the norm. Considering these potential factors of influence on voting behavior of participants in the TV-Show, we investigate whether they can help to explain why participants do not seem to evaluate each other with a zero.

In chapter 5, "*Come Dine with Me*: a Game-Theoretic Analysis", we interpret popular the TV-show *Come Dine with Me* as a simultaneous non-cooperative game with evaluation levels as strategic variables, and show that it belongs to a class of strategic games which we call *mutual evaluations games*. Any *mutual evaluation game* (MEG) possesses a *zero equilibrium*—i.e. a Nash equilibrium where all players evaluate each other with the lowest available scores—as well as numerous *non-zero equilibria*. Since the *zero equilibrium* is an equilibrium in weakly dominant strategies, it may arguably be regarded as *the* canonical equilibrium. Yet, in 212 rounds of the German format of *Come Dine with Me* contestants never achieved this equilibrium, nor did they (with one exception) play any other equilibrium. We provide potential explanations for this behaviour by considering the impact of social pressure and reputation mechanisms, bandwagon effects, inequality aversion and sequential voting effects.

The chapter is based on a cooperation with Prof. Thorsten Upmann from the University of Duisburg-Essen, Mercator School of Management. It is published in the CESifo Working Paper Series, No. 4138.

Finally, chapter 6,"Pro-Social behavior in the TV format *Come Dine with Me*: An empirical investigation", considers the influence of social approval and reputation on voting behavior in the German version of the TV format *Come Dine with Me* from an empirical point of view. We test whether reputation, social in-game influences, objective quality, or personal traits impact the voting behavior of participants, with a dataset running from 2006 to 2011. We find that the objective sophistication of a meal, the order of cooking, whether a person has already cooked, and the social similarity between contestant and evaluator all have a significant influence on the evaluating behavior. These findings help to improve the understanding of the impact that reputation and social approval have on economic decision making.

The chapter is based on a cooperation with Prof. Thorsten Upmann and Daniel Weimar from the University of Duisburg-Essen, Mercator School of Management, and Prof. Harald Tauchmann, from the University of Erlangen-Nürnberg.

Chapter 2

Technology Transfer Mechanisms and International Cooperation to Combat Climate Change

2.1 Introduction

International cooperation to combat human induced climate change has so far not been very effective. Even though there are a significant number of signatories to the Kyoto protocol, it is often only considered a test-stage with limited impact. The real cooperative effort that will be necessary is yet to come. Developing countries do not face CO2 emission limits under the protocol. But since they will be responsible for the largest increase in emissions in the future this situation is unsustainable. Developed countries are historically responsible for most of the emissions currently circulating in the atmosphere. Therefore, the argument is made by developing countries that they should shoulder most of the abatement. Also, abatement in developing countries is considerably less expensive than abating in developed countries. This gives room to negotiate the terms, according to which developing countries are willing to accept emission limits.

We propose a new technology transfer mechanism, which we label Green Technology Banks (GTB) as a side-payment within a new climate change agreement. We make the following assumptions: Developing and developed countries accept emission limits, but global emission markets are imperfectly linked, in the sense that emission rights cannot simply be bought in one market and used in the other. Furthermore, not all sectors in a region are regulated by emission caps. The central research question we seek to address is how this mechanism performs according to the following criteria: Environmental effectiveness, technological effectiveness, economic efficiency, incentives for participation and administrative feasibility. We find that the mechanism performs well according to these criteria, the largest obstacle being the acceptance of emission limits by developing countries. We show that the incentives for developing country companies and governments are substantial and should compensate them for the accepting emission limits. We do not specify exact amounts of emissions saved due to the mechanism, since this crucially depends on the outcome of the negotiations process, which has proven to be highly unforeseeable.

The paper is structured as follows: Sections 2 and 3 present a brief overview on the issues that are most important concerning technology transfer as part of international climate change agreements. In section 4 the technology transfer elements of the Kyoto Protocol, the APP, and the most recent decisions taken at the conference of the parties meeting in Cancún and Durban are analysed. In section 5 the GTB is laid out and evaluated according to the previously mentioned criteria. Section 6 concludes.

2.2 Global Public Goods and International cooperation

2.2.1 Global Public Goods

The global public good of a stable climate is affected by a range of externalities. The most significant one is the insufficiently priced negative externality of emissions caused by the conversion of fossil fuels into energy, leading to potentially drastic climatic change involving potentially substantial costs. A second important externality related to climate change concerns the research and development (R&D) of technologies that help to adapt or mitigate climate change. Concerning the issue of R&D related to global environmental problems, Hoel (2005) show that if countries only consider the impact that R&D has on their own economy whereas the full effect is global, R&D levels on climate technology are sub-optimal. Without an international agreement, countries will only equate the marginal benefit of R&D with the marginal environmental costs within their own borders. But R&D can lower abatement costs globally. Climate technology might still reach other countries due to spill-over effects. These technological spill-overs can reduce the CO2 "leakage effect"[1], which occurs when no global agreement is in place. (Hoel and Golombek, 2005).

2.2.2 International Cooperation

Solving transboundary issues of pollution requires cooperation from at least two states, in the case of climate change cooperation from most of the world (Stern, 2007). In contrast to pollution issues that happen within the borders of a state, there is no agency that can force states to adhere to agreements made between them unless they delegate that role to an international agency and decide to give up sovereignty. In the case of human induced climate change this has not happened so far. The Kyoto protocol in its current form does not have a favourable cost-benefit ratio for Annex I countries when contrasting the costs that they have to incur in order to fulfil their abatement obligations with the probable benefits they would obtain from damages avoided in the future (Barrett, 2007). Whereas this cost-benefit ratio was 1:11 for the Montreal Protocol for the participating industrialized countries, this ratio stands at 1:0.5 for the Kyoto Protocol for Annex I parties (Barrett, 2007). These numbers rely on results from estimations carried out by Nordhaus and Boyer (1998). They recently revised their numbers and the ratio now stands at 1:1.7 (Nordhaus, 2008). One way to increase the benefits of accession to

[1]The magnitude of the leakage effect is still under discussion (Paltsev, 2001; Kallbekken et al., 2006).

an agreement is via side-payments, commonly referred to as “carrots”. (McGinty, 2006) and (Barrett, 2003) show that asymmetry combined with side-payments can substantially increases the number of signatories to an agreement compared to the non-cooperative symmetric situation, the former for the case of climate change and the later for ozone depletion.. Asymmetry in the context of climate change and technology can be linked to at least three dimensions: Marginal costs of abatement (Ellerman et al., World Bank Policy Research, 1998; Nordhaus and Boyer, 1998), green technology and damages caused by climate change (Stern, 2007; IPCC, 2007a). These asymmetries give scope for transfers from developed to developing countries.

2.3 Green-technology

2.3.1 Obstacles to an optimal allocation of green-technology

Three major obstacles hinder the spreading of already existing green-technology and environmental R&D at sufficient levels taking into account its global effects. First of all, it is largely produced by private companies in developed countries and it is protected by patents that make it often unaffordable for governments and entrepreneurs in developing countries (Aghion et al., NBER Working Paper, 2007; Teng et al., Harvard Project on International Climate Agreements Discussion Paper,2008). Secondly, developed for conditions prevalent in industrialized countries, it cannot easily be used in developing countries. In addition to this, developing countries often do not have the capacity to adapt the technology to local circumstances (Arnold and Bell, 2001). Finally, there is no common and easily accessible database or information source that gives a concise overview about the developments in the field of green-technology and environmental R&D: “Technology infrastructure such as data collection and dissemination, and training of scientists and engineers is likely to be seriously underprovided by market incentives alone.” (Jaffe et al., 2005, p.173). This lack of information combined with the two previous hindrances results in a suboptimal adoption of green-technologies.

2.3.2 Green-Technology and the benefits of technology transfer

The primary benefits of replacing a fossil fuel based infrastructure in developing countries (IEA, 2008; Teng et al., Harvard Project on International Climate Agreements Discussion Paper,2008) is a reduction in CO2 emissions, contributing to the global public good of a stable climate. But one should also consider the ancillary benefits that accrue to developed and developing countries under GHG mitigation policies and transfer of green-technology. Examples of ancillary benefits inherent to GHG policies are an increase of habitat for endangered species, less soil erosion under re-forestation, and reduction of other pollutants such as NOx, SO2, N2O, which lead to positive health effects (Rübbelke and Pittel, 2008). These benefits occur mostly in the short-run and have the characteristics of a domestic public good (Rübbelke and Pittel, 2008) Ancillary benefits that are likely to occur specifically with technology transfer are: A more efficient production process, higher product quality, reduced energy loss and an improved design of material (Jochem and Madlener, 2003). Furthermore, developing countries that can acquire new technology via such a transfer have the chance to leapfrog between 20-40 years of technological development and are likely to see a dramatic increase in resource efficiency. Concerning technological capabilities and learning (Arnold and Bell, 2001, p.302) note: "An important omission from the available accounts of catch-up development is the creation and role of 'mid-level' craft and technician skills, which are crucial to the absorption and use of production technologies and to a great deal of innovative activity not classed as formal R&D." Therefore, skills which are usually omitted from classical innovation studies focusing on R&D spending are also likely to profit significantly from technology transfer. Finally, a movement away from bio-mass to either more efficient oil heating or usage of renewable energies should dramatically increase the productivity of poor households due to health benefits and less time necessary for the collection of bio-mass (Sagar, 2005).

2.4 Current climate change protocols and technology transfer

The following analysis of the Kyoto Protocol and the APP will focus on technology transfer elements of the two. For a more general review of technology agreements we point the reader to de Coninck et al. (2008), who provide an excellent overview and assessment over a range of technology agreements related to the mitigation of climate change.

2.4.1 Kyoto Protocol

As mentioned above, the world does not only suffer a global externality from climate changing emissions but also a lack of environmental related R&D that deals with climate change relevant emissions. That externality is not sufficiently addressed in the Kyoto protocol. There is no mechanism that would allow countries to take into account the global effect of environmental related R&D, which leads to an under provision (Hoel, 2005). Even if the permit trade that takes place under the Kyoto

Protocol equalizes marginal abatement costs in participating regions and induces more environmental R&D as a market "pull" effect (Jaffe et al., 2005; Lawrence, 2007), the level is still likely to be insufficient. A "pull" incentive can come from increasing taxes on the undesirable economic good, fossil fuels in this case. A "push" incentive can come in the form of research, better information or subsidies. (Hoel, 2005, p.59) notes:"... there will be too little R&D expenditure in the Kyoto type agreement even if total emissions are set equal to what they are in the first-best optimum". Furthermore, the permit trade does not have any provisions in itself addressing the issue of technology transfer between Annex I and Annex II parties. Technology transfer may take place through technological spill-overs, but most likely at levels that are insufficient.

The only way in which technology transfer is indirectly addressed in the protocol is via its two mechanisms, the CDM and Joint Implementation (JI). The JI will not be analysed in further depth here, as it concerns transfers from developed to developed countries. Technology transfer is not a necessary condition for projects under these mechanisms to take place. A study by Seres (2007) finds that about 39% of CDM projects claim to involve technology transfer. What exactly is meant by technology transfer is not specified under CDM regulations. These projects are responsible for 64% of all emission reductions achieved under CDM, which points to the fact that it is often large projects that involve technology transfer. About 56% of projects that involve technology transfer claim to transfer equipment and knowledge, 32% involve only knowledge. Projects with knowledge transfer alone account for about 11% of all technology transfer projects.

The CDM has been subject to several lines of criticism over the years. The main concern has been directed towards baseline methodology issues, which lead to a significant oversupply of emission credits, depressing emission permit prices (Wara, 2008b; Bakker et al., 2011b). Other points of criticism concerned its actual contribution to sustainable development, the lack of technology transfer, the distribution of projects worldwide (95% in Asia and Latin America), and the level of transaction cost involved in getting a project approved (Bakker et al., 2011b). A possible fix to these problems would be better enforcement. But enforcement comes at the price of higher transaction costs and many worthwhile projects especially at a smaller scale are then unlikely to be carried out (Hagem and Holtsmark, SSB Discussion Paper, 2009).

2.4.2 APP

First announced at the 38th ASEAN Ministerial in Vientiane, Laos in 2005 the Asian-Pacific Partnership on Clean Development and Climate (APP) was officially launched in July 2006. One of the purposes of the partnership is to, "Create a voluntary, non-legally binding framework for international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging and longer term cost- effective, cleaner, more efficient technologies and practices among the Partners through concrete and substantial cooperation so as to achieve practical results."[2] Eight public-private task forces have been created in order to achieve this purpose in different sectors, these are: Aluminium, building and appliances, cement, cleaner fossil energy, coal mining, power generation and transmission, renewable energy and distributed generation and finally steel. Currently the US, Australia, Canada, Japan, South Korea, India and China are members to the APP. Together, they account for more than 50% of global climate change relevant emissions. de Coninck et al. (2008) classify the APP as a knowledge sharing and coordination agreement. This implies that emission limits are absent, limiting the incentive to adopt new technology since the "push" side is absent (Lawrence, 2007). Also, two important sectors that are globally responsible for a substantial amount of emissions have no task force assigned to them in the APP. The two sectors are agriculture and transportation, responsible for 13.5% and 13.1% respectively of global greenhouse gas emissions (IPCC, 2007b). de Coninck et al. (2008) note that they expect effectiveness to be low given current the small budget allocated to the initiative. The US has promised US$ 65 million for its first year of operation (Lawrence, 2009). Australia had promised US$ 150 million over the next 5 years (Lawrence, 2007) and recently reduced this to US$ 100 million per year (Lawrence, 2009)). Compared to the actual need for investment of US$ 10-100 billion annually this sum seems meagre (Haegestand and Skjaerseth, 2009), even more so when considering that the members of the APP are responsible for more than 50% of global emissions. In the Montreal protocol developed countries had an obligation via a certain formula to pay for the incremental cost of developing countries for acceding to the agreement. In the case of the APP this is voluntary and the outcome seems to be disappointing.

2.4.3 Outcomes from recent Conference of Party Meetings

During the Conference of the Parties Meeting (COP) in Cancun meeting in December 2010, it was decided to create a Technology Executive Committee (TEC) and a Climate Technology Centre and Network (CTCN). The TEC Panel of experts will consist of 11 developed country and 9 developing country experts, which are responsible for "identifying technology needs and priorities, coordinating efforts, and providing recommendations for improvement"[3]. CTCN," ...consisting of a centre and a large network, will serve an operative role in technology transfer on an international to regional scale. It will function mainly to carry out the TEC's directives,

[2] http://www.asiapacificpartnership.org/english/about.aspx

[3] http://www.climaticoanalysis.org/post/cancun-agreements-on-technology-transfer/

as well as to facilitate and improve upon existing initiatives."[4] Furthermore, a Green Climate Fund (GCF) was established with equal representations from developed and developing countries[5]. This fund should raise 100 billion $ per year by 2020. During its initial period it will be governed by the World Bank, afterwards by the UN. At COP 17 in Durban in December 2011, it was decided to extend the Kyoto Protocol for a second commitment period until 2017 or 2020, depending on the speed of the negotiation process for a new agreement, which is supposed to be finalised by 2015. Also, the operational details of the TEC and CTCN were finalised and both are expected to become fully operational in 2012. Furthermore, the GCF was formally launched: "The Fund will contribute to the achievement of the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC). In the context of sustainable development, the Fund will promote the paradigm shift towards low-emission and climate-resilient development pathways by providing support to developing countries to limit or reduce their greenhouse gas emissions and to adapt to the impacts of climate change, taking into account the needs of those developing countries particularly vulnerable to the adverse effects of climate change"[6]. The host country of the GCF secretariat and further operational details are scheduled to be worked out and decided upon by the end of 2012. However, it is still not clear where the money for the fund is supposed to come from which remains the largest obstacle for a fully operational GCF (Padma et al., 2011). Additionally, it is not clear how and if at all the GCF would be linked with the TEC and CTCN. If sufficient funding can be raised for the GCF and it is institutionally connected with the TEC and CTCN, this would represent a significant improvement to current approaches. Finally, it is not clear how the fund and technology transfer would be integrated into emission markets, if a new agreement emerges. As argued above, this is a vital step for an effective climate change agreement.

2.5 Green Technology Bank

The GTB is based on the idea advanced by Barrett (2001, 2003) and Benedick (2001, 2007) that a global agreement to curb emissions should be more technology-centred. Their approach focuses on the operational details of R&D funding and technology standards whereas the question of technology transfer was mentioned only briefly. The GTB also shares some elements with the technology CDM (tCDM) by Teng et al. (Harvard Project on International Climate Agreements Discussion Paper,2008). The most crucial difference between the tCDM and the GTB is the

[4] http://www.climaticoanalysis.org/post/cancun-agreements-on-technology-transfer/

[5] http://unfccc.int/files/press/news_room/press_releases_and_advisories/application\newline/pdf/pr_20101211_cop16_closing.pdf

[6] http://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdfpage=55

underlying assumption that developing countries do not face emission ceilings under the tCDM. Common to both proposals is their requirement that technology transfer must be part of any emission credit transfer, which is absent in the CDM in its current form. Without this requirement there is a serious risk of energy infrastructure being "...locked-in" to a carbon intensive mode."(Teng et al., Harvard Project on International Climate Agreements Discussion Paper,2008, p.7). Furthermore, the tCDM will only grant a transfer of emission rights, if the transfer of technology is in line with goals of the developing country government, such as "installation of transferred technology, or a cost reduction goal, or a local content goal." Teng et al. (Harvard Project on International Climate Agreements Discussion Paper,2008). Such restrictions are not part of the GTB. They would be too exclusive for the mechanism to fulfil its potential in terms of technology transfer from developed to developing countries.

The GTB addresses the operational details left out by Barrett (2001, 2003) and Benedick (2001, 2007) concerning technology transfer. It is embedded in a global agreement with emission limits also for developing countries, a crucial assumption left out in the Teng et al. (2008) approach. Therefore, it represents an option for a very different policy scenario than their approach. In comparison to the CDM it includes a technology transfer dimension previously absent. Finally, in contrast to the APP it is embedded in a climate change agreement that features emission limits.

2.5.1 Assumptions underlying the GTB

First of all, the assumption is made that technology is a private good that has a range of positive externalities. Technology here is first and foremost considered to be technical apparatus. The soft-skills that come with it, such as better technical knowledge fall under the category of externalities, as well as ancillary benefits. Secondly, it is assumed that in the foreseeable future there will be no global permit market but rather several regional permit markets that are imperfectly linked. Furthermore, these regional permit markets will not be perfect in the sense that not all sectors of the economy will be regulated by emission caps or taxes, especially in developing countries. One implication of this is different abatement cost levels in different regions of the world, leaving room for a side-payment mechanism. Finally, as the GTB is to operate under a climate change agreement that imposes emission limits on developed as well as on developing countries, any permit transfer that takes place will be a zero sum game in terms of global total emissions. If a transfer takes place, one country will have to give up emission permits in order for the transacting partner to acquire them.

The assumption of one or several regional agreements and the establishment of emission markets by developing countries might not be observed now or in the coming years. Therefore, the following analysis is first and foremost a theoretical exercise applicable in the circumstances assumed, rather than an option for the current policy situation. However, developing countries will have to follow a lower emission path then industrialized countries did, even if a global agreement is unlikely to emerge anytime soon in order to reduce the likelihood of drastic climate change (Roegeberg et al., 2010). Otherwise, it will be highly unlikely that emissions can be lowered enough globally to fulfil the two degree target. This necessity in combination with concessions required by developed countries can result in sectoral or regional limits for developing countries making linkage of emission markets with technology transfer a viable option (Pizer, Harvard Project on International Climate Agreements Discussion Paper, 2008; Rose and Wei, 2008).

2.5.2 Informational basis and governance

Under the GTB, developed countries are to establish a database containing information about green-technologies available from the public and the private sector in developed and developing countries. This database would be accessible to all actors for free, making information about the availability of green-technology accessible essentially for free. The actual construction plans would still be protected by patents. Therefore, the database would not contain proprietary information. The goal of the database is to create a common platform that is widely known and accepted in order to provide up-to-date information in the field of green-technologies to reduce the search costs for the private and public sector in both developed and developing countries. Developed countries should bear the financial responsibility for setting up the operation. Public and private research institutes as well as firms and governments from both developing and developed countries can contribute to the database. The information provided in the database can be accessed by firms, research institutions and governments from both developed and developing countries for free. These actors can use the information to identify technologies that are suitable for projects they are about to undertake.

An organisation that is well placed to provide such a service the recently founded International Renewable Energy Agency (IRENA): "...IRENA will facilitate access to all relevant renewable energy information, including technical data, economic data and renewable resource potential data. IRENA will share experiences on best practices and lessons learned regarding policy frameworks, capacity-building projects, available finance mechanisms and renewable energy related energy efficiency measures"[7]. Most of the financial funds IRENA receives come from developed countries, but a sizeable number of developing countries are also financing members, ensuring

[7] http://www.irena.org/ourMission/index.aspx?mnu=mis

the necessary expertise to identify technologies suitable to local circumstances in developing countries.

2.5.3 The mechanism

A company sells green-technology to company in a developing country. The government of the company that buys the technology either buys the emission rights from the buying company if it is subject to emission caps, or buys them in the regional emission market if a company is not subject to emission caps. The government of the company that sells the technology then buys these emission credits from the other government and transfers them to the company that sold the technology. The emission permits received by the selling company can now be used in the regional market of that company to either lower their abatement requirement, or to sell them in the market. These emission permits can only be used in the regional market of the selling company. The opportunity to sell emission credits in the regional permit market is crucial since it allows selling companies that are not regulated by emission caps to gain from increasing R&D into green-technology. Figure 2.1 and 2.2 illustrate the transfer for regulated and non-regulated companies.

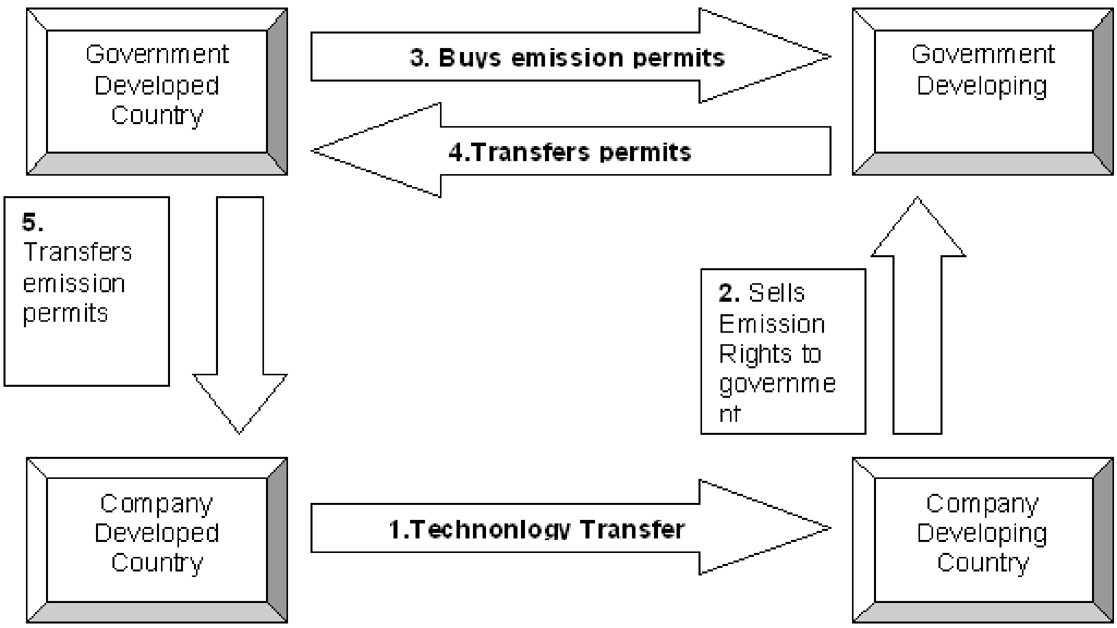

Figure 2.1: Technology Transfer among companies subject to emission caps

Technology that is already easily accessible in the buying country should be excluded from the scheme, as in the tCDM. How many emission credits are transferred depends on the evaluation of the amount of emissions that have been avoided compared to the Business-As-Usual case (BAU). An exact determination of how many emissions were avoided could be carried out by similar institutions as the ones that are currently responsible for this task under the CDM. Governments are involved to ensure a smooth transfer of emissions rights on an international level. These tasks could as well be delegated to IRENA, the United Nations Environmental Program (UNEP) or the United Nations Framework Convention on Climate Change (UNFCCC). It should be emphasized here that despite the involvement of the government the incentives are set in such a way that they especially aim at increasing technology transfer activity originating from the private sector.

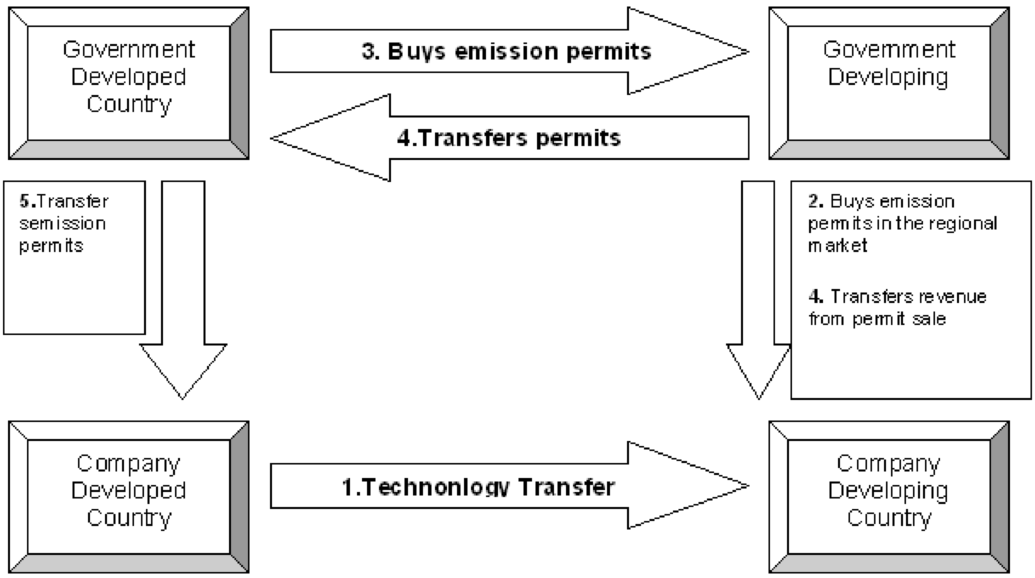

Figure 2.2: Technology Transfer among companies not subject to emission caps

Due to the permit transfer the price of emission rights in the regional market of the technology buying countries will increase since supply is reduced. However, the assumption is made here that the level of the price increase will not be substantial enough to offset the benefit of a decreased price of green-technology. The price in the selling countries is likely to fall, since the amount of permits in the market increases.

A regular evaluation should take place if the emission credit transfer alone is enough to induce sufficient R&D in green-technology. If this is not the case, then the developed country government should consider providing subsidies in addition to emission credits. The group of people that carry out such an evaluation should be comprised of developed and developing countries experts. Again, IRENA and its centre for innovation and technology, but also the UNEP or the UNFCCC would be suitable candidates for this task

2.5.4 Evaluation of the GTB

We evaluate the GTB by a set of criteria common in the literature for TOA: Environmental effectiveness, technological effectiveness, economic efficiency, incentives for participation and administrative feasibility. Environmental effectiveness evaluates how effective a mechanism reduces CO2 emissions and what kind of policy certainty it provides to participating factions. In terms of CO2 reductions the GTB does not change the total amount of allowed emission in the developed world which is governed by local Emission Trading Systems (ETS). However, it should increase the incentive for developing countries to participate in a new climate change agreement that stipulates emission limits for them. Naming a specific number of additional CO2 reductions which could be attributed to the GTB would be too speculative at this point in our opinion. Much depends on the negotiation process which has proven to be highly uncertain. Concerning predictability, CDM projects throughout the last years often suffered from delays and non-issuance, due to baseline methodology disputes (Bakker et al., 2011b; Cormier and Bellassen, CDC Climat Research Working Paper, 2012). This would be a problem for the GTB as well, but this issue would be a problem for any kind of TOA that involves sustainable emission reductions as a goal, which require a baseline definition. A TOA is considered as technological effective if it advances science and technology, taking into account the kind of technology it focuses on. The GTB's focuses on marketable technology and providing better information about it worldwide. In both areas, it could lead to a significant improvement of the knowledge and application of environmental technology in developing countries. In the medium- to long-term the GTB can lead to an increase in green R&D focused on applications in developing countries. This increase in R&D activity would not only be observed in the developed world, but also in developing countries since the influx of environmental technology can be expected to lead to an increase in technological capabilities and learning as argued above. Concerning economic efficiency, the GTB does not prescribe the type of technology that is supposed to be used. This is left for the involved companies to decide. However, the GTB does have sustainability requirements on the technology involved. We consider this is as a necessary condition for an environmentally sound TOA. Concerning administrative feasibility IRENA, UNEP, and the UNFCCC were mentioned. Also, the recently established CTCN and TEC should play an important role in administrating the mechanism. Combined, these institutions have the experience and international reach to successfully manage the GTB. Also, many developed country governments have had experience with emission trading and are also in a good position to facilitate the required emission permit exchange and consult developing country governments to set up their own ETS. The following sub-sections describe the incentives for buying and selling companies, and for governments to participate in the GTB.

2.5.5 Incentives for technology buying companies

Buying companies subject to tradable emission caps can now obtain technology at a lower price than before. This is due to the standard tax/subsidy incidence. Furthermore, buying companies that are not subject to emission caps receive an actual subsidy besides the decrease in the price of technology. The money paid by the selling company's government for the emission credits will be transferred to them. Since non-regulated companies do not have the same "pull" incentive (Lawrence, 2007) to adopt green-technology as their regulated peers, an additional incentive to do so is important. Companies in developing countries which do not accept emission limits under a new climate change agreement will not be able to profit from the GTB. Therefore, companies should have an interest in pressuring their respective government to join the agreement in order to gain access to green-technology via GTB, as it reduces their cost of operation and offers them technology that might otherwise be hard to come by.

2.5.6 Incentives for technology selling companies

Both types of companies, those subject to an emission limit and those not subject to emission limits, receive a subsidy from their government in form of emission credits. It is crucial to realize that non-regulated companies also receive a subsidy since they can sell the emission rights that they receive through the transfer in the regional emission market. Otherwise, they would have no added incentive for green technology R&D applicable in developing countries. Both companies still receive the normal price for their technology; the subsidy in form of emission permits is additional. Finally, The more known the GTB is in buying countries, the more beneficial participation will be as developed and developing country entrepreneurs will use it as a standard tool to find and offer green-technologies. This has the potential to reduce marketing and search costs for both sides.

2.5.7 Incentives for governments

Developing country governments profit through extensive ancillary benefits as described above. Furthermore, they profit through the establishment of permit markets by gaining an additional revenue source in the medium-term. Developed country governments lessen the burden on their companies by giving them cheaper abatement options. On the cost side they bear the main financial burden for the mechanism. All governments profit from reducing the chances of drastic climate change by reducing emissions globally.

2.6 Conclusion

This paper evaluated a new technology transfer mechanism as part of a new climate change agreement that involves emission limits for both developed and developing countries under the assumption of regional emission markets. Several insufficiencies of current climate change agreements concerning the effective transfer of technology were addressed. The Kyoto Protocol has no effective technology transfer mechanism and major developing and developed country polluters are not part of the agreement. The Clean Development Mechanism (CDM) suffers from range of disadvantageous economic incentives that may even lead to more emissions. The Asia-Pacific Partnership on Clean Development and Climate (APP) features no emission limits reducing the "pull" incentive to adopt green-technology considerably. The funding of the agreement has been meagre so far. The sectoral approach concerning the development and transfer of technologies deserves credit and can serve as an input for the development of a more effective technology transfer scheme. An important actor that both the Kyoto Protocol and the APP fail to include through economic incentives at a sufficient scale is the private sector. Without the inclusion of this sector and its R&D capacity, it is unlikely that sufficient transfer of technology will materialize. Current discussions in Cancun and Durban led to the establishment of the Technology Executive Committee, a Climate Technology Centre and Network committee and the Green Climate Fund, which is supposed to reach a volume of 100 US$ billion by 2020, funding abatement and mitigation activities. The origin of the funding is still not clear. Furthermore, it is not clear how these newly established mechanisms will operate within the framework of separated emission markets.

Based on the need to include a more technology transfer centred element in a new climate change agreement we proposed a new technology transfer mechanism, which we labelled Green Technology Bank (GTB). Developed countries are to establish a database containing information about green-technologies available from the public and the private sector in developed and developing countries. Developing countries are required to establish emission markets with binding limits in order to be part of the mechanism. Emission permits from developing countries are used to subsidise technology transfers from the developed world. Developed country governments would compensate developing country companies for transferring permits to developed country companies.

We evaluated the GTB according to the following criteria: Environmental effectiveness, technological effectiveness, economic efficiency, incentives for participation and compliance, and administrative feasibility. The GTB achieves additional emission reduction compared to other technology-oriented agreements by requiring developed countries to accept emission limits, making it environmentally more effective. However, this requirement makes the implementation of the mechanism more problematic since no developing country has accepted an emission limit up until now. Nevertheless, we consider this to be a necessary requirement since otherwise a TOA might actually lead to more emissions. Concerning technological effectiveness, marketable green-technology is the primary technology targeted. In the medium- to long-run R&D directed towards green-technology suitable for developing country conditions is likely to increase as well. Involved companies are free to pick the technology they want to employ if it has been approved by the GTB under the conditions described above. Therefore, keeping the sustainability and additionally criteria in mind the GTB can be considered as economically efficient and cost-effective. Concerning incentives for participation, companies in developed countries receive subsidies for technology transfer and a lower permit price due to the influx of permits from developing countries. Companies in developing countries receive otherwise hard to come by technology but face higher emission prices. Developed and developing country governments reduce the chance of drastic climate change by agreeing to a solution, in which developing countries accept emission limits. Developed countries pay for the mechanism, but considering the establishment of the GCF and the proposed financial backing a willingness to pay seems to there. Developed country governments profit from ancillary benefits and revenues from the emission markets.

Further research on this issue should aim at answering questions related to product piracy, potential negative effects of technology, an empirical estimation of avoided emissions, the political feasibility of such a scheme considering recent developments, and how to integrate such an approach with official development aid efforts.

Chapter 3

The Clean-Development Mechanism, Stochastic Permit Prices and Energy Investments

3.1 Introduction

Negotiations to reach a legally binding international agreement to combat climate change are on stalemate and proposals to postpone the final deadline to reach an agreement in 2015 have been put forward (Kossoy and Guigon, 2013). However, despite of the slow pace of international negotiations, several countries are planning to set up their own cap-and-trade based Emission Trading Schemes (ETS) in the near future. These include Australia, China and Korea (Kossoy and Guigon, 2013). Thus, the question of how these markets will interact with each other and how the baseline-credit-schemes such as the Clean Development Mechanism (CDM) will continue to function in such a setting is of great importance. Besides the CDM the Joint Implementation Mechanism (JI) is another flexible mechanisms based on provisions in the Kyoto Protocol. A program that is likely to join their ranks in the foreseeable future is the United Nations Collaborative Initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD).

Uncertainty about a future climate change agreement and the way ETS markets are going to interact will have a major influence on future profit stream of energy companies. Furthermore, investment in the energy sector is generally considered as irreversible. Combining uncertainty and irreversibility with the possibility of waiting for new information to make a better informed decision, renders this problem suitable for an uncertainty analysis framework in the spirit of real-options analysis. This method is superior to calculating net present value (NPV) in such a situation, since the investor can take into account future realizations of the parameters that influence profitability, allowing him to optimally time the investment decision. An NPV analysis assigns a probability to these outcomes, but is not able to consider future market realizations, and react in a flexible manner to these. Since it does not take into account the flexibility dimension, it is also likely to yield a lower value of the investment project compared to the real-options approach. After the original development of financial options valuation by Black and Scholes (1973) and Merton (1973), their techniques were adopted for real-investments in the physical sense by Myers (1977). Dixit and Pindyck (1994) and Trigeoris (1996) provide a good overview with numerous examples. One of the first adoptions to the energy sector was undertaken by Herbelot (1992). Analyzing the decision of a coal-power plant owner to install a scrubber to fulfill sulfur emissions limits, he finds that the net present value (NPV) increases substantially when the owner can decide flexibly when to start investing, due to the value of additional information. Insley (2003) investigates the same problem and finds that the low level of emission prices since 1993 led to few investment decision in favor of scrubbers, while the preferred method of compliance was switching to a low-sulfur coal type. The option to halt construction at any point played pivotal role in the investment decision. Yang et al. (2008) investigate the impact of uncertain emission prices on the risk associated with investing either into a coal, gas or nuclear plant. They find that the degree of the investment risk caused by uncertain permit prices depends to a large degree on the merit-order of energy production, being lowest when gas or nuclear plants are first. Furthermore, including the possibility of price shocks, policy makers should try to let them happen as seldom as possible since investment will stagnate while waiting for new information on prices to be revealed. In contrast, Fuss et al. (2009) consider the case when a company can invest into a fossil, a carbon-capture and storage (CCS) module, and/or a renewable power plant. The owner is flexible with respect to the timing of investment and permit prices evolve stochastically. They find that when evaluating these options simultaneously, the option to retrofit the fossil plant with CCS leads to a postponement of the investment into renewable energy. Also, when considering the timing of climate policy they find that longer periods between jumps in prices lead to less emissions. Fuss et al. (2010) consider the impact of options on emission permits that are derived from REDD on energy investments. They find that REDD options may leave investment in carbon capture and storage technology (CCS) unaffected if they are priced as derivatives of CO_2 permits, since this would ensure a high enough price. However, one should not forget that CCS will remain a non-viable technology option for the medium-term future, and testing has even been banned in some countries [1].

Studies that investigate the impact of the CDM on the option value of a gas power plant with a simultaneous renewable investment option under uncertainty in the developed world are largely absent in the literature. Some publications address the issue on a qualitative level[2], while others address the issue on a Computable General Equilibrium level that does not incorporate the uncertainty dimension (Anger et al., 2008). However, as mentioned before new cap-and-trade emission markets are emerging world wide and without an overarching structure of a global climate agreement, baseline-credit-markets such as the CDM will continue to play a role. Without a good understanding of how the interaction between these two markets influence the investment decisions of energy companies, it is not clear ex-ante that they will help to transform the energy infrastructure and strengthen sustainable

[1] `http://www.n-tv.de/politik/Wie-ein-Ausweg-zur-Sackgasse-wurde-article4376091.html`

[2] See for example (Blanco and Rodrigues, 2008, p.1517):"However, the low price of CERs and ERUs (Emission Reduction Units) on the EU ETS market can play an indirect negative role on wind energy and other technologies since their inflow to the EU ETS market further reduces the allowance prices in Europe and with them the little incentive that remains to invest in-house. An industry obliged to cut its emissions would prefer to import cheap JI or CDM credits instead of buying EU ETS credits or adapting its production process.".

development, which are the two foremost goals of the CDM[3].

The contribution of this paper is to analyze the impact that the simultaneous availability of the two permit classes with differing price developments, one from a cap-and-trade scheme and one from a baseline-credit-scheme, has on the option value to invest into a gas power plant, or a renewable alternative. We use the EU ETS as an example for a cap-and-trade scheme and the CDM as an example of baseline-credit scheme, since these are the dominant permit classes at the moment. We take the perspective of a government asking the following questions:

- What is the probability that in t years the value of the option to build a gas plant is larger than investing into a wind power plant under permit price uncertainty?
- What is the impact of being able to use permits originating from the Clean Development Mechanism on this probability?

The answer to the first question allows the government to evaluate if a policy environment leads investors to build wind power plants now, or if companies are willing to postpone their investment and choose gas power due to the option value of fossil energy. If it is the goal of a government to promote renewable energy investment, taking into account the option value of fossil energy is very important since this might significantly prolong a fossil based energy structure. Answering the second question then helps to evaluate the impact of different permit classes on investment behavior, which is of importance as more and more permit markets with different price developments paths emerge around the world and are likely to be linked in the future.

In order to answer these questions, we employ a simplified real options framework where a single investor compares the option value to invest into a gas power plant to investing into a wind power plant. The uncertainty a gas plant faces stems from the price development of the two permit classes which are described by two geometric Brownian Motions (gBM). Since the wind power plant does not produce any CO_2 emissions, it can be considered as risk free with respect to permit costs, and no option value is calculated for this energy type. For given permit prices the value of the option to build a gas power plant are calculated. We then determine the probability of the following event at time t: An investor facing the choice between the gas power plant option and building a wind power plant, chooses the gas plant option. Furthermore, the impact of increasing or decreasing the quota of sCER

[3]"The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3" - http://unfccc.int/essential_background/kyoto_protocol/items/1678.php

permits a company can use is simulated. Finally, we perform a range of sensitivity checks with respect to the interest rate, the trend of the gBM, volatility of permit prices and the correlation between the two process.

The rest of the paper is organized as follows: Section 2 introduces briefly the most important background issues, the CDM, the carbon market and the behavior of emission prices analyzed in the literature. In Section 3 the model is described, including the price-processes of the two permit classes. Section 4 contains the data information used in the model, concerning energy markets, the power plants, and the price processes. In Section 5 we present and discuss the results of our model, and draw policy conclusions. In section 6 we conclude.

3.2 A short history of the carbon market an the CDM

3.2.1 The Carbon Market

The carbon market is largely dominated by European ETS transactions, being currently the only large scale mandatory ETS market in operation worldwide. The overall volume and the importance of the CDM have been growing steadily, coming to a halt in 2009 due to the uncertainty over a new climate change agreement. With a total value of 141.9 $ billion dollars in 2010, the European ETS represented 82% of the market volume and the CDM 14% (Linacre et al., 2011). There are two asset classes pertaining to the CDM. The first is primary Certified Emission Reductions (pCER). These are credits that are obtained directly from projects. The second class, secondary Certified Emission Reductions (sCER), are resold pCER. The main difference between the two pertains to delivery risk. sCER do not have a delivery risk, since they have been delivered already. However, this is a major issue with pCER. Regulations concerning what projects are CDM eligible change frequently and might discontinue an already existing permit flow (Bakker et al., 2011a; Klepper, 2011). Therefore, it is uncertain if pCER will eventually be generated from a project. Despite the fact that they have already been delivered, the delivery risk of pCER does carry on to sCER in that without a constant stream of new permits from CDM projects, the market will eventually become illiquid thus influencing the sCER price (Linacre et al., 2011; Mansanet-Bataller et al., 2011).

3.2.2 The CDM

The CDM gives developed countries flexibility in achieving their emission targets and should lower their compliance cost, since abatement activities carried out in developing countries are considerably cheaper (Castro, 2010; Bakker et al., 2011a). The CDM operates as follows: Companies can invest into projects in developing countries, receiving the emission saved due to their involvement as emission permits. In order to establish the amount of emissions that were saved due to the involvement of the developed country firm, a baseline is established estimating the business-as-usual emissions. Therefore, the CDM is also called a basline-and-credit scheme. The credits in form of emission permits a company obtains in this way, can then be used in their regional ETS to fulfill their own abatement requirements or can be re-sold in the market. Projects should only fall under the CDM if they would not have been carried out without CDM support, and additional emission savings are generated due to the CDM involvement (Zavodov, 2010). This is known as the additionality criterion. CDM projects do not need to have a technology transfer component. A study by Seres et al. (2009) finds that about 36% of all CDM projects have a technology transfer component. There is a limit on how many CDM permits can be used for abatement in the European ETS. This limit is set at 13,4% of the total of allowed emissions for Phase II, which runs from 2008-2012 (Kossoy and Ambrosi, 2011).

The CDM has been subject to a variety of criticism over the years. One main line of criticism concerns the additionality criterion. Often, projects that would have gone ahead without the CDM were reported in such a way to make them CDM conform (Wara, 2008a; Bakker et al., 2011a). This in turn led to an oversupply of CDM credits and consequently depressed emission prices. Other criticism concerns its actual contribution to sustainable development, the lack of technology transfer, the distribution of projects world wide (95% in Asia and Latin America), and the level of transaction cost involved in getting a project approved (Bakker et al., 2011a). How and if these criticisms will be incorporated into a post-2012 climate change agreement is not clear at the moment. However,"... the CDM will last well into the post-Kyoto phase, since the majority of projects already approved will lead to the issuance of CERs (*permits*) for many years to come" (Klepper, 2011, p.696)

3.2.3 Emission Prices

One European Emission Allowances (EUA) and one sCER can be used to abate the same amount of CO_2. Therefore, they should theoretically have the same value. However, this is not the case. Since the CDM became operational in 2007 and the establishment of its different asset classes in the market, a spread existed between sCER and EUA allowance prices. This spread can be linked to the political uncertainty that has constantly threatened the functioning of the CDM market. The future of the CDM has often not been clear and the approval process of credits has undergone frequent changes, so that investors do not perceive this permit class as an equivalent of EUA permits (Mizrach, 2012). This uncertainty is likely to persist in the coming years, which implies that the spread will continue to exist (Bellassen and Leguet, 2012).

Mansanet-Bataller et al. (2011) investigate the drivers of this spread and find the following factors to be the most influential: Linking the CDM with other ETS, the EUA price, the financial crisis, and the volume of EUA and sCER traded. Linking with other ETS markets is an important issue since demand for permits originating from the CDM would increase, thereby decreasing the reliance of CDM projects on the European ETS market. With the current quota, liquidity is limited on the market (Nazifi, 2011). The spread is also driven by the EUA-Price since this sets effectively the upper limit for sCER prices. If the price of the sCER were to surpass the EUA price, it would make no sense for an investor to buy these unless there were no more EUA available on the market. Since industrial production was significantly lowered during the financial crisis, less emissions were produced and consequently also less permits required. This led to a significant over-supply of EUA and this brought the sCER and EUA price closer together. Finally, the volume of trading points to the fact, "...that the EUA-sCER spread maybe used as a 'speculative' instrument by rational investors and market participants on the EU ETS, who are able to trade simultaneously EUAs and sCERs when the price difference is large enough to justify the arbitrage activities" (Mansanet-Bataller et al., 2011, p.1067).

3.3 Model Description

3.3.1 Price-processes

In our model we will focus on the impact of EUA and sCER on energy investments. We exclude pCER from our analysis for three reasons: First of all, there is no common pCER price since each project has an individual risk class and therefore an individual price (Mansanet-Bataller et al., 2011). This would force us to include a stochastic process for every project type, which would render the model intractable. Secondly, including pCER would also imply that we would have to include the decision to invest into a CDM project. We will not pursue this modeling approach, since there are many firms in the market that are not able to develop CDM projects, but are subject to emission limits and rely on the sCER market. Finally, pCER transactions do not play a significant role in the current market situation and are unlikely to play a major role within the next five years.

We assume that prices for EUA and sCER allowances follow stochastic processes. For EUA prices we follow current results in the literature that attempt to model their price development (Yang et al., 2008; Fuss et al., 2008, 2009, 2010), by assuming the price development to follow a geometric Brownian motion (GBM) with a positive trend. The basic reason for using GBM to model the price process, is that it is generally expected that prices for allowances will reach a higher long-term price than the current one, despite possible price reductions from time to time. The goal of a long-term higher price stems from clearly formulated political will to achieve a relatively carbon free economy in the long-term in order to limit severe consequences of global warming. For the sCER price we also assume a GBM with a positive trend. A more detailed discussion concerning the sCER price process specification will follow in section 4.2.

Let $(\Omega, \mathcal{F}, \mathbb{P})$ be a probability space and let $W_{1,t}$ and $W_{2,t}$ be Wiener processes with respect to a probability measure $\mathbb{P}$ with correlation $\rho < 1$. Let $(\mathcal{F}_t)_t$ be the filtration generated by $W_{1,t}$ and $W_{2,t}$. The price processes $P_{1,t}$ and $P_{2,t}$ are described by the following equation:

$$\frac{dP_{i,t}}{P_{i,t}} = \mu_i dt + \sigma_i dW_{i,t}. \tag{3.3.1}$$

Hence $P_{i,t}$ is a stochastic processes following a GBM, where $i = 1, 2$. Here $P_{1,t}$ models the price process for EUA and $P_{2,t}$ the price process for sCER. Here μ_i is the drift parameter, σ_i the volatility parameter. In such a situation, an equivalent martingale measure exists which we denote by $\mathbb{Q}$ [4]. Under this probability measure the two price processes discounted by the risk-free interested r_f are martingales.

We assumed $W_{1,t}$ and $W_{2,t}$ to be correlated because the EUA prices have a positive influence on sCER prices (Mansanet-Bataller et al., 2011). The intuition for this influence is as follows: An increase in the price of EUA will increase interest in buying sCER allowances due to their now relative lower price, assuming that the quota for sCER allowances has not been reached yet. This will drive up the sCER price and therefore we expect the correlation to be positive.

3.3.2 Profit function and investment options

An investor can choose between pursuing an investment project in gas or wind power, by comparing the real-option value of the gas plant, with that of a wind power which does not face uncertainty. By considering the real-option value and not the NPV value, the investor can take into account the effect of the realization of future permit prices. Since the investment can be postponed, taking account of these realizations will render a gas power investment more profitable as compared to the NPV approach. This will give the government a better informed analysis

[4] see Shreve (2004) for details

concerning the effect of a policy framework on investment behavior. For simplicity, we assume that both power plants have the same life time of 30 years, denoted by T. Capital used for the construction of one type of plant cannot be used for the construction of the other or resold, thereby making the investment irreversible. The wind power plant is emission free and receives a subsidy in form of a premium on the electricity price for its production. This renewable subsidy simulates a feed-in tariff system, which is a common support system for renewables in many countries. If the gas plant is built, a company needs to comply with emission regulations. We assume that this will be done by acquiring sCER and EUA emission permits. As described above, there is a maximum limit imposed on the amount of sCER that can be used for abatement. We assume that if emission permits need to be purchased, a company will use the maximum quota of sCER, and buy EUA to fulfill the rest. This assumption is based on empirical results that companies that are involved in the CDM market are using their full CDM quota (Hermann et al., 2010). As on of the main purposes of the CDM is to reduce the abatement cost of developed countries, and sCER prices are lower and likely to remain so (Mizrach, 2012; Bellassen and Leguet, 2012), this behavior can be expected. Furthermore, this assumption makes the model considerably more tractable and numerically easier to handle than allowing a continuous choice model. Since the empirical evidence points to the fact the full quota is used, we are convinced that even with this assumption our model can generate valuable insides concerning the impact of permit classes on investment behavior. The sCER price can surpass the EUA price in our model. This assumption is only used to keep the computational complexity manageable. This is a limitation of our model, but we believe it does not overly limit the conclusions we derive from this model.

The question we seek to answer is: At time 0, what is the probability that an investor prefers the gas plant over the wind plant investment? In order to answer this question we look at the profit functions of the power plants, which are defined as follows: For both plants, let

- q be the amount of electricity produced,
- c_e be the price of electricity and
- r_f be the risk-free interest rate,

For the wind plant, let

- $V_{w,year}$ be the yearly profit of the plant,
- s_w be the subsidy the wind plant receives for the electricity produced
- r_w be the risk-adjusted interest rate for the plant,

- C_w be the construction costs,
- OC_w be the operation costs per unit of electricity produced,

where $V_{w,year} = q(c_e + s_w - OC_w)$. Then the present value at time t_0 of a wind plant built at t_0 is,

$$V_w = \sum_{t=t_0+1}^{t_0+T} \frac{V_{w,year}}{(1+r_w)^{t-t_0}} - C_w = \sum_{t=1}^{T} \frac{V_{w,year}}{(1+r_w)^t} - C_w.$$

Note that V_w is independent of t_0, P_1 and P_2.

For the gas plant, let

- $V_{g,year}^-$ be the yearly profit of the plant, if permits prices are not considered,
- r_g be the risk-adjusted interest rate of the plant except for the permit costs,
- n be the number of permits needed per year,
- p be the percentage of sCER permits,
- C_g be the construction costs.
- OC_g be the operation costs per unit of electricity produced,
- c_g be the fuel cost for gas per unit of electricity produced,

where $V_{g,year}^- = q(c_e - c_g - OC_g)$. Then,

Proposition 1. The present value V_g at time t_0 of a gas plant built at time t_0 is,

$$V_g^- - nT((1-p)P_{1,t_0} - pP_{2,t_0}),$$

where

$$V_g^- := [\sum_{t=1}^{T} \frac{V_{g,year}^-}{(1+r_g)^t}] - C_g.$$

Proof. Let $F_{1,t}$ and $F_{2,t}$ be the futures price of a EUA permit and a sCER permit at t_0 with delivery date t. Then

$$V_g = [\sum_{t=t_0+1}^{t_0+T} \frac{V_{g,year}^-}{(1+r_g)^{t-t_0}} - \frac{n((1-p)F_{1,t} + pF_{2,t})}{(1+r_f)^{t-t_0}}] - C_g.$$

The first summand $\frac{V_{g,year}^-}{(1+r_g)^{t-t_0}}$ is the yearly profit of the gas power plant, if permit prices are not considered, discounted by the risk-adjusted interest rate. The second summand $\frac{n((1-p)F_{1,t}+pF_{2,t})}{(1+r_f)^{t-t_0}}$ are the discounted permit costs, that is the value at t_0 of the obligation to buy a permit at time t. In the absence of arbitrage this value is precisely the futures price at t_0 with delivery t discounted by the risk-free interest rate. The future prices are given by $F_{i,t} = P_{i,t_0}(1+r_f)^{t-t_0}$ (for example, see Hull (2009) Chapter 5). We get

$$\begin{aligned} V_g &= [\sum_{t=1}^{T} \frac{V^-_{g,year}}{(1+r_g)^t} - n((1-p)P_{1,t_0} - pP_{2,t_0})] - C_g \\ &= V_g^- - nT((1-p)P_{1,t_0} - pP_{2,t_0}), \end{aligned}$$

□

Note that V_g depends on P_{1,t_0} and P_{2,t_0}, but not on t_0 itself. We will sometimes write $V_g(P_{1,t_0}, P_{2,t_0})$ to indicate this dependency.

For the precise values of the variables defined above such as the operation costs and energy prices, we refer the reader to Section 3.4.1.

3.3.3 The value of a gas power plant option

We now value the following gas plant investment option. Let L be natural number. Each year, beginning at time t_0, the investor can decide whether or not build one. Once the gas plant is built, the investor has no further option. If the plant is built, it has to be built within L years. So if the option is exercised, it has to be exercised by time $t_0 + L$. We denote the value of this option at time t, where $t_0 \leq t \leq t_0 + L$ by $V_{o,t}$. If the plants has not been built at time t and $t < t_0 + L$, the value of the option is given by

$$V_{o,t}(P_{1,t}, P_{2,t}) = \max\{E_{\mathbb{Q}}[\frac{V_{o,t+1}}{(1+r_f)}|\mathcal{F}_t](P_{1,t}, P_{2,t}), V_g(P_{1,t}, P_{2,t})\}. \tag{3.3.2}$$

On the right hand side of the above equation, $E_{\mathbb{Q}}[\frac{V_{o,t+1}}{(1+r_f)}|\mathcal{F}_t]$ is the continuation value, that is the expected value of the option at time $t+1$ under equivalent martingale measure $\mathbb{Q}$ if the investor does not build the plant at time t. The value $V_g(P_{1,t}, P_{2,t})$ is the payoff the investor receives if he decides to build the gas plant at time t. At time $t_0 + L$, the continuation value is 0, because this is the last time the investor can decide to build the gas plant. Hence

$$V_{o,t_0+L}(P_{1,t_0+L}, P_{2,t_0+L}) = \max\{V_g(P_{1,t_0+L}, P_{2,t_0+L}), 0\}. \tag{3.3.3}$$

We will solve these equations (3.3.2) and (3.3.3) recursively. Again, note that the value V_{o,t_0} of the option at time t_0 depends on P_{1,t_0}, P_{2,t_0} and L, but not on t_0 itself.

In the case that only EUA permits are used, that is $p = 0$, the above option can be expressed as a classical American Put option.

Proposition 2. If $p = 0$, then

$$V_{o,t_0} = nT\,\mathrm{Put}_{Amer}(\frac{V_g^-}{nT}, L),$$

where $\mathrm{Put}_{Amer}(x, t)$ is the value of an American Put option on P_1 with strike price x and maturity date t that can be exercise each year.

Proof. If the option to build a gas plant is exercised at time t, the payoff is

$$V_g^- - nTP_{1,t} = nT(\frac{V_g^-}{nT} - P_{1,t})$$

by Proposition 1. That is the same payoff one receives when exercising nT Put options with strike price $\frac{V_g^-}{nT}$. □

In Table 3.1 we show the option value for different EUA/sCER price combinations.

Table 3.1: Gas plant value in million dollars *(*$p = 0.15$*)*

EUA \ sCER	2	5	10
2	1087.8	1069	1037.8
5	981.6	962.9	931.6
10	804.7	786	754.7
20	450.9	432.1	400.9
30	97	78.3	47.1

Table 3.1: Gas plant value in million dollars

In figure 3.1 and figure 3.2 we plot the value of V_{o,t_0} for permit price values $\in [0, 40]$. The plot in figure 3.1 contains the case $p = 0$, where V_{o,t_0} just depends on P_{1,t_0}. We choose L to 30. By Proposition 2 the values can be determined using the algorithm from Longstaff and Schwartz (2001) for pricing American put options. Of course, we did not calculate the option value for every possible value of P_{1,t_0}, but determined the option value for over 1000 different value of P_{1,t_0} between 0 and 80 and then calculated a best fit curve for those option values. In figure 3.2 we plot the value of V_{o,t_0} when $p = 0.15$. In this situation V_{o,t_0} depends on both P_{1,t_0} and P_{2,t_0} and we calculated the value of V_{o,t_0} for up to a thousand different pairs of values of P_{1,t_0} and P_{2,t_0} between 0 and 80. For the calculation of each of these values, we generated 2000 paths for each of the price processes randomly. Given these paths, we then solved (3.3.2) and (3.3.3) recursively. That means we first determine V_{o,t_0+L} using equation (3.3.3), and recursively use the already calculated value of $V_{o,t+1}$ to determine $V_{o,t}$ using (3.3.2). As in the Longstaff and Schwartz algorithm, the continuation value is determined by a least square approximation.

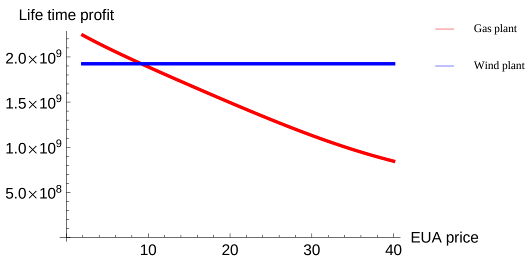

Figure 3.1: Option Value / EUA only

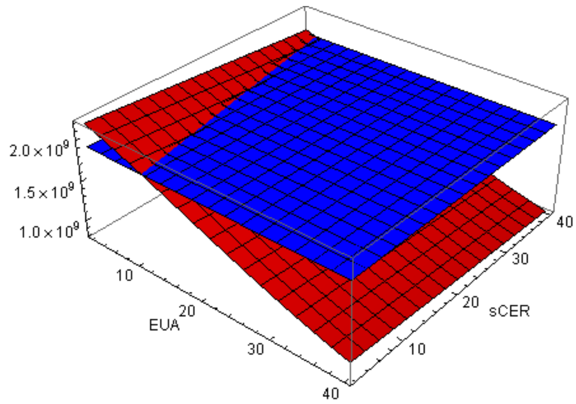

Figure 3.2: Option Value / EUA and sCER

3.3.4 Investment Probability

We are now interested in the probability at time 0 that at a future time t_0 an investor prefers the gas plant option over building a wind power plant. This happens precisely when at time t_0, $V_{o,t_0}(P_{1,t_0}, P_{2,t_0}) > V_w$. Thus we want to calculate

$$\mathbb{P}(V_{o,t_0}(P_{1,t_0}, P_{2,t_0}) > V_w). \tag{3.3.4}$$

Note that $\mathbb{P}$ here is the actual real-world probability measure. It is *not* the risk-neutral measure $\mathbb{Q}$. The reason is that we take the point of view of an government that is trying to determine with what probability an investor makes a certain decision. We are not trying to determine the risk-neutral value for governments of such a decision by the investor.

Since V_{o,t_0} depends only on the values of the two price processes P_{1,t_0} and P_{2,t_0} at time t_0, but not on t_0 itself, we do not have to determine the value $V_{o,t_0}(P_{1,t_0}, P_{2,t_0})$ for each t_0 and each possible value of P_{1,t_0} and P_{2,t_0}. Rather it is enough to determine $V_{o,t_0}(P_{1,t_0}, P_{2,t_0})$ for one t_0 and each possible value of P_{1,t_0} and P_{2,t_0}. The calculation of this option value was discussed in the previous subsection. This allows use to determine a set $C \subseteq \mathbb{R}^2$ such that a pair $(x, y) \in \mathbb{R}^2$ is in C if and only if $V_{o,t_0}(x, y) > V_w$ for all possible values of t_0. In Figure 3.2, the set C is where the red plane is above the blue plane.

Hence in order to calculate the probability in (3.3.4), we just need to determine $\mathbb{P}((P_{1,t_0}, P_{2,t_0}) \in C)$. The following the Proposition gives a formula for this probability.

Proposition 3. Let $t_0 > 0$. Then

$$\mathbb{P}((P_{1,t_0}, P_{2,t_0}) \in C) = \frac{1}{2\pi t_0} \int_{(x,y)\in D} e^{-\frac{1}{2t_0}(x^2+y^2)} dxdy,$$

where D is

$$\{(x, y) \in \mathbb{R}^2 \ : \ (P_{1,0}e^{(\mu_1-\frac{\sigma_1^2}{2})t+\sigma_1 x}, P_{2,0}e^{(\mu_2-\frac{\sigma_2^2}{2})t+\sigma_2(\rho x+(1-\rho^2)^{1/2}y)}) \in C\}$$

Proof. Let $W_{3,t}$ be another Wiener process with respect to a probability measure $\mathbb{P}$ that is independent of $W_{1,t}$. Without loss of generality, we can assume that

$$W_{2,t} = \rho W_{1,t} + (1 - \rho^2)^{1/2} W_{3,t}.$$

Then the solution of the stochastic differential equations (4.3.2) are

$$\begin{aligned} P_{1,t} &= P_{1,0}e^{(\mu_1-\frac{\sigma_1^2}{2})t+\sigma_1 W_{1,t}} \\ P_{2,t} &= P_{2,0}e^{(\mu_2-\frac{\sigma_2^2}{2})t+\sigma_2 W_{2,t}} \\ &= P_{2,0}e^{(\mu_2-\frac{\sigma_2^2}{2})t+\sigma_2(\rho W_{1,t}+(1-\rho^2)^{1/2}W_{3,t})} \end{aligned}$$

The equation in the statement of the Proposition now follows immediately from the fact that $W_{1,t}$ and $W_{3,t}$ are independent and normally distributed with mean 0 and variance t. $\square$

So after C is calculated as described in the previous section, the probability in Proposition 3 can now be determined using numerical integration.

Table 3.2: Electricity Generating Cost

	CCGT	Onshore Wind
Electricity price ($)	81	81
Subsidy ($)	0	27
Generation Capacity (MW)	480	45
Capital cost (overnight cost) ($/kW)	1,068.00	2,348.00
Fuel Cost (US$ /MWh)	36,45	0
O&M ($ /MWh)	4.48	21.92
CO_2 emissions (tCO_2/MWh)	0.33	0
Load Factor	85%	26%
Lifetime	30 years	25 years
Risk-adjusted rate	4%	4%
Risk-free rate	2%	2%

Source: IEA (2010); EEX (2014)

Table 3.2: Electricity Generating Cost

3.4 Data

3.4.1 Power Plant Data

Table 3.2 lists costs and CO_2 emissions of the different power plants [5]. These are derived from "Projected Costs of Generating Electricity - 2010" (IEA, 2010) and current market data from the European Energy Exchange (EEX) (EEX, 2014). We compare a combined cycle gas turbine (CCGT) with an onshore wind power plant, since gas is likely to remain more competitive than coal and nuclear power given current events and costs (Kaplan, 2008). We choose not to consider large offshore wind power plants since there is currently too little information available on their cost structure which will experience steep learning curves in the future. In contrast, onshore wind power has already profited from significant technological progress and is considered a mature technology. In order to make a comparison possible based on the above provided data, an investor has to effectively produce 480 MW in our model, either with a gas or wind power plant[6].

We assume that operation & maintenance cost (O&M) as well as capital cost are deterministic. Since both power plants are mature technologies, it is reasonable to expect that changes in production and investment costs would occur in a similar

[5]All € values are converted into $ values at an exchange rate of 1.35 $/€.

[6]For a gas power plant this implies a required plant size of 565 MW ($\frac{480MW}{0.85(LoadFactor)}$). The load factor is the average yearly usage of the full capacity of the power plant. A wind power plant with a capacity of 1,920 MW is required to achieve an effective production of 480 MW. This is approximately equal to the investment into 1,5 average CCGT or a wind park with approximately 43 on-shore wind mills.

fashion. Capital cost can be considered as overnight cost, which are the cost that would apply if the plant could be constructed overnight[7]. Using overnight costs for two different types of plants is a valid assumption, if the lead time does not differ substantially which is the case for wind and gas power (IEA, 2010; Kettunen et al., 2011).

We assume a deterministic electricity as well as gas price. Construction costs for either power plant type also remain deterministic throughout the model. We thereby abstract from inflation on the cost as well as on the revenue side. These assumptions are made to reduce modeling complexity significantly and to put the focus on the effect of allowance prices on power plant investments, the foremost topic of this paper. The assumption of a deterministic electricity price is not uncommon in similar modeling approaches (Laurikka and Koljonen, 2006; Fuss et al., 2008). Furthermore, it has been shown that changing to a stochastic process would not lead to significantly different results in similar model approaches (Fuss et al., 2008). The electricity price is set at 60 € which lies approximately in between the medium-term baseload and peak market price (EEX, 2014) [8]. Renewable energy currently receives a range of support besides the indirect support of putting a price on CO_2 emission. We choose to incorporate these various form of support via a price premium for wind energy on the electricity price. Concerning the size of the subsidy, we took the German market as an example. In the German case, on-shore wind receives initially a very high premium, which can last up to 13 years (Wikipedia, 2014). The premium is then slowly reduced to match market prices. Based on the current feed-in tariff structure, on-shore wind energy then receives a premium of approximately 20 € per MWh. In section 5.3, we report the results for different levels of support. Concerning the deterministic gas price, long-term contracts are common for gas deliveries and current research estimates a stable mean-reverting trend for gas prices in Europe (Abadie and Chamorro, 2006; Boogert and de Jong, 2011). Finally, we do not consider technological progress since both power plants types are mature technologies which we assume to experience similar speed of technological improvement in the long-term, which leaves the overall investment decision unaffected.

Since we did not include inflation in our model, we focus on the real risk-free and risk-adjusted interest rates. In our baseline scenario we assume a 2% risk-free rate based on yields of 3-months US treasury bills (Siddiqui et al., 2007) and a 4%

[7]"The overnight cost therefore excludes escalation in equipment, labor, and commodity prices that could occur during the time a plant is under construction. It also excludes the financing charges, often referred to as interest during construction (IDC), incurred while the plant is being built". (Kaplan, 2008, p.696)

[8]All data stemming from the EEX website, the electricity, gas and permit prices, were taken on the 22. January 2014.

risk-adjusted rate (Kaplan, 2008; IEA, 2010; Kettunen et al., 2011). We assume the same risk-adjusted rates for both types of power plants since they only reflect the construction and operation risk. The risk originating from emission permit prices is priced using no arbitrage arguments. We also run the model with a set of different interest rates and provide the results as part of our sensitivity checks in section 5.

3.4.2 Permit Prices and volatility

Permit prices are subject to great uncertainties due to the influence of climate policy which changes frequently. Also, due to the relatively short existence of permit markets, especially in the case of CDM permits, there is no long-term data available (Fuss et al., 2010). We take future prices of EUA and sCER as a point of departure [9]. In accordance with current literature and modeling, we assume that the trend of the EUA price is 5% and the volatility 20% (Fuss et al., 2010; Kettunen et al., 2011). We want to stress again here that the assumption of a 5% trend originates from the political goal to limit global climate change to 2°C. If carbon markets are used as the main tool to achieve this goal, a 5% trend generates the necessary incentives to achieve this.

For the sCER permit class, we assume the same volatility as for the EUA permits, since sCER strongly depend on the EUA market and the political uncertainty is likely to remain high for both permit classes. Furthermore, we assume in our baseline scenario that the price spread between the two classes is likely to widen over time, due to the fundamentally different nature of the market for the two permit classes. This expectation can be seen in our first scenario configuration, where the trend of the EUA gBM is 5% and that of the sCER gBM is 3%. We also report the results for a range of different trend values. The main factors likely to cause this differential development are the emergence of new emissions markets worldwide causing increasing supply and demand and larger liquidity (Nazifi, 2011; Mansanet-Bataller et al., 2011; Bellassen and Leguet, 2012). The increase in supply and demand is due to the fact that there is still a large amount of untapped projects which will likely be picked up by new emission markets evolving around the world at cost similar to current projects (Castro, 2010; Bakker et al., 2011a). These new emissions markets will also represent a new source of demand for permits originating from the CDM. With increasing demand and supply due to new markets, the dependence of the CDM on the EU ETS will lessen over time, increasing the liquidity of the whole market (Mansanet-Bataller et al., 2011). The most recent example of this is Australia, which expects most of the allowances during the first years of its ETS to be covered by CDM credits (Fogarty, 2011). Furthermore, it can be expected that the

[9] EUA:4.45 €; sCER:0.45 €Data from http://www.eex.com Date: 22.01.2014

Table 3.3: Price Process Data

	EUA	sCER
Trend	5%	3%
Volatility	20%	20%
Starting Price ($)	6	0.6075
Correlation sCER-EUA	0.1-0.9	

Table 3.3: Price Process Data

regulations on new ETS markets will tighten slower than on the EU ETS markets. Therefore, the price increase of those permits is likely to be slower than in the EU ETS market, which will decouple the price development of sCER from the likely steeper price increase of EUA permits, leading to an probably even larger spread between EUA and sCER prices (Bellassen and Leguet, 2012).

As mentioned above, we assume that the sCER and EUA price process are correlated. Chevallier (2011) tests for correlation in a multivariate GARCH Model. He finds correlations ranging from 0.01-0.9. Therefore, we use 0.5 for the three policy scenarios we investigate and perform sensitivity checks for a range of other values.

3.5 Results

3.5.1 Policy Scenarios

In this section, we first present three policy scenarios and their results by calculating the integral in Proposition 1 using numeral integration in Mathematica. We then discuss the results and a range sensitivity checks.

In scenario 1 we assume that there will be no significant change in the regulatory environment. The EU leaves the quota of how many CDM credits can be used at roughly 15%. The EU ETS market also remains the dominant carbon market in the world, which means that the degree of correlation between the two prices also remains high [10]. In the second scenario, we assume that the regulation concerning the amount of CDM permits is loosened by increasing the quota to 30%. The EU ETS market still remains the main global carbon market and the correlation of sCER and EUA stays at 0.5. One policy scenario in which the quota would increase is if new offset mechanisms such as REDD would be introduced into the market.

In order not to reduce the CDM market to a level that would leave it illiquid

[10] We assume a value of $\rho = 0.5$

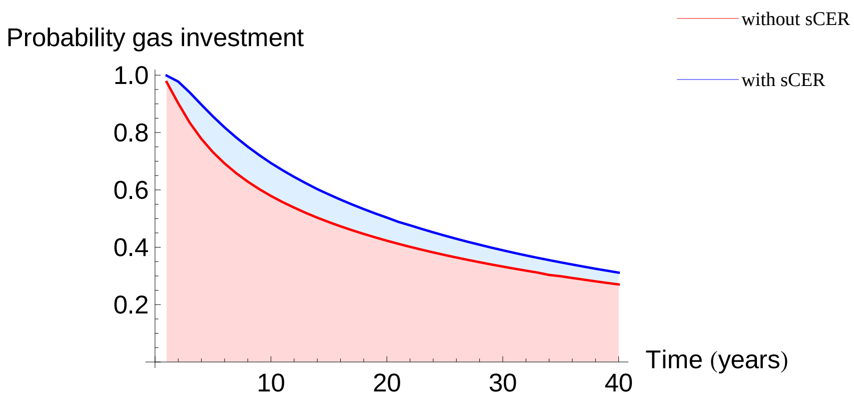

Figure 3.3: Scenario 1, Correlation = 0.5, sCER Quota:15%

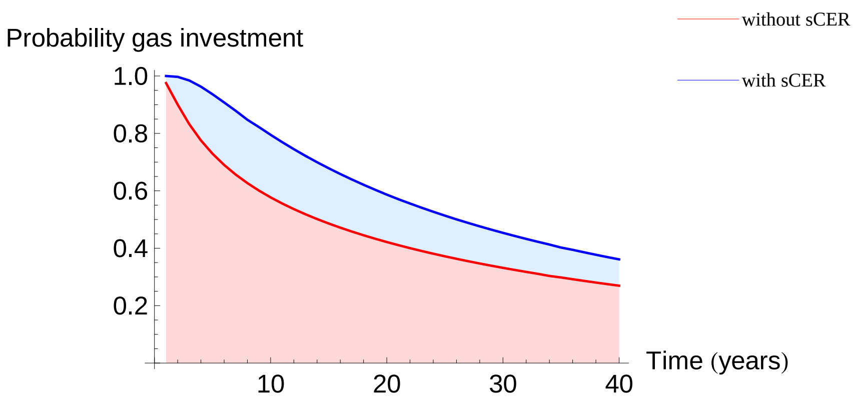

Figure 3.4: Scenario 2, Correlation = 0.5, sCER Quota:30%

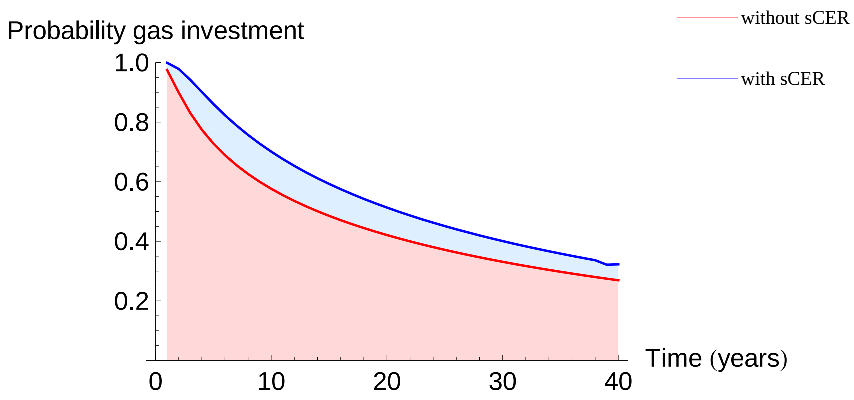

Figure 3.5: Scenario 3, Correlation = 0.1, sCER Quota:15%

it is possible that policy makers would add a REDD allowance quota on top of the CDM quota. This reasoning implies that REDD allowances will exhibit the same behavior as CDM allowances, which is taken as an assumption here since no data on the value of REDD permits is available. In our third scenario we assume that new carbon markets emerge world-wide in which the CDM can also be used for abatement, reducing the correlation between the Wiener processes to 0.1. The quota of allowed offset permits remains at 15%. In all simulations presented below the volatility was set at 20%. We compare the case where no sCER can be purchased to the different scenarios above. Therefore, the case when power plant operators can only buy EUA permits is our baseline case, represented in all figures by the red line. All figures show the probability that an investor will choose to build a gas power plant at a certain point in time.

In figure 3.3 we can observe that gas power remains the dominant investment choice until around year 10 if sCER permits cannot be used. The blue area describes the investment difference caused by sCER over the whole time horizon. With sCER this period is prolonged for a few more years. After this period, wind power quickly becomes the more likely investment choice, as we can see from the downward sloping probability curve. The availability of sCER does not only prolong the period in which investing into wind power is highly unlikely. They also cause a difference in later years. Figure 3.4 shows the results for scenario 2. We can observe that doubling the sCER quota leads to a significant change as compared to scenario 1 since the blue area increases significantly. The time when sCER starts having an influence is equal. Figure 3.5 shows the results of testing if a change in the correlation between the Wiener-Processes has a significant impact. When comparing the results to scenario one, where all inputs are the same besides the correlation rate, we see that there is no significant change as compared to scenario 1.

3.5.2 Discussion and sensitivity checks

What we can observe from the figures 3.3-3.5 in general is that the incentive to invest into wind energy even without the possibility to acquire sCER permits in either scenario remains low until until around year 10 increasing rapidly afterwards.. When sCER permits can be used, gas power investments become more lucrative. Even though the investment probability into gas decreases equally fast as in the EUA only scenario, the investment probability over the whole time horizon increases. As a sensitivity check for our results we consider a range of interest rates, volatilities, wind energy premiums, and trend values. We use the values from scenario 1 as a standard and report the changes in values we made below the figures. Scenario 1 is always in the middle of the set of figures that follow now, in order to make the comparison easier. The left and right side represent a decrease/increase in value we check for sensitivity respectively.

Testing for changing interest rates, we find that lower risk-adjusted interest rates lead to a higher investment probability for wind power. As an example we show how changing the risk adjusted rate to 3-5% impacts investment in Figures 3.6-3.8. We do not report the results for changing the risk-free interest rate, as these changes led to no significant change of the results.

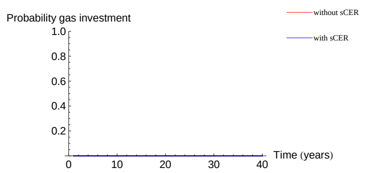

Figure 3.6: Risk free rate 2%; Risk adjusted rate 3%

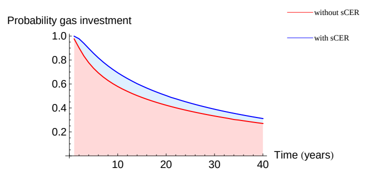

Figure 3.7: Risk free rate 2%; Risk adjusted rate 4%

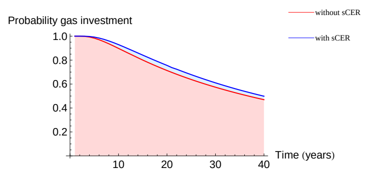

Figure 3.8: Risk free rate 2%; Risk adjusted rate 5%

When using the same specification as in scenario 1 and changing the interest rates to 3% (risk adjusted) and 2% (risk free), we find that gas power is not an investment choice anymore. This significant change stems from the fact that wind power becomes more profitable relative to gas power since emission prices increase over time. The less this future profit is discounted, the more profitable wind power becomes today. Thus, in an infinite time horizon model wind power would always be the more profitable than gas power despite the large investment cost difference[11].

[11]In our model the investment cost into a wind power plant is 4,334,769,230 US $ as compared

Consequently, when increasing the interest rate to 5%, the investment likelihood of gas increases. This also shows that the two power plants are already very similar in terms of cost, when considering a longer time period and increasing permit prices.

Secondly, we test for three different volatility values. Figures 3.9-3.11 show the effect of changing volatility from 10% to 20%, and then to 30%. Increasing the volatility leads to a higher probability that at a certain point in time an investor decides to invest into a gas power plant. This effect is more pronounced as we move along the time axis. A high level of volatility generally increases the value of options, since the value of the new information that arrives increases and it pays to wait for this information to materialize. In the context of our model a high volatility implies a higher chance in later periods that the emission price can be very low, rendering gas power investment more likely.

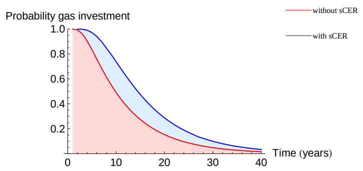

Figure 3.9: Volatility 10%

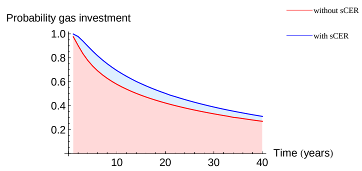

Figure 3.10: Volatility 20%

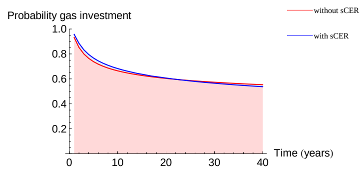

Figure 3.11: Volatility 30%

Thirdly, we consider different levels of the wind premium. Figures 3.12-3.14 show the impact the subsidy has in investment behavior for the levels 10 €, 20 €, and 30 €.

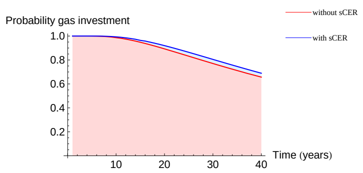

Figure 3.12: Premium 10€

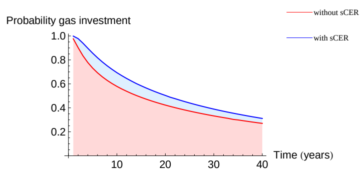

Figure 3.13: Premium 20€

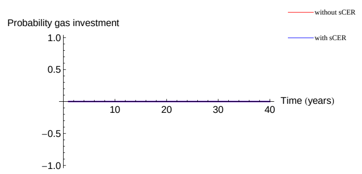

Figure 3.14: Premium 30€

When the premium is only 10 €, investing into wind power becomes very unlikely even towards the end of the time horizon. In contrast, at a level of 30 €wind power is so profitable that the investor start to build wind power plants from the very

to 603,105,882 US $ for a gas power plant.

beginning. This is not surprising as a 30 € subsidy implies a 50% mark-up over the market price. More interesting is that the 10 € premium is not sufficient to induce significant wind power investment over the whole time horizon. If policy makers have the goal to promote renewable investments in the medium term, a 20 € premium seems to be the necessary. However, such a result should be treated with care as we do not consider a range of other effects that impact investment behavior, such as the interrelation between emission, gas and electricity prices. What can be stated is that a premium is still necessary for wind energy up until the medium term, if it is a policy goal to promote investment into wind energy.

Finally, we test different trend values for the sCER price process (Figures 3.15-3.17). Increasing the trend value for sCER lowers the positive effect of sCER on gas investments. This is intuitively appealing, since a higher trend value will lead to a lower gap in between sCER and EUA permits in later years rendering gas investment less profitable. However, even if both price processes have a trend value of 5%, the possibility of using sCER still has a positive effect on the investment probability in gas power.

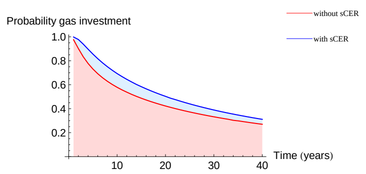

Figure 3.15: sCER Trend=3%, EUA Trend = 5%

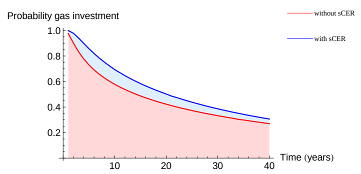

Figure 3.16: sCER Trend=4%, EUA Trend = 5%

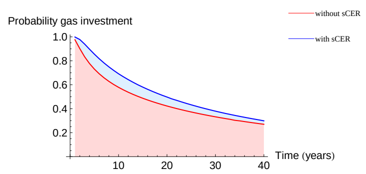

Figure 3.17: sCER Trend=5%, EUA Trend = 5%

The results presented here should be treated with care, since we assume two stochastic price processes which represent a best guess of the future based on previous modeling approaches in the literature and the current political situation. Also, since we simplified the model as much as possible in order to focus on the effect of the sCER permit class Many interacting features of energy markets, such as the dependence of the gas and electricity price on emission permit prices, have been left out. Including them would have resulted in an identification problem of the sCER effect. Leaving them out means that changes to the functioning of the permit market might not have the same effect as in our model, since other effects such as the interdependence of natural resource markets can overcompensate any effect stemming from permit markets. Therefore, the general direction of the effect should be taken as the main result of our simulations, not specific results for each year.

By conducting a range of sensitivity checks we could show which factors are crucial to the investment decision, namely the interest rate, the wind premium and volatility. The interest rate is the most crucial factor, as small changes can already trigger large differences in investment decision. This is not surprising considering the length of the investment decision we are considering here and the profit profile of gas power plants. Gas power plants are very profitable at the beginning with low permit prices. As prices rise, they become increasingly less profitable and the more this effect is discounted, the higher the incentive of the investor to choose wind power plants.

3.5.3 Policy implications

The results presented in the model are not meant as a tool for investment decision making for firms, rather they should inform policy makers about the probable consequences of a certain policy framework. Therefore, we do not provide a fixed date when investment into either power plant type takes places, rather we provide the probabilities to indicate the most likely event and to see the development over time. This goal and also limitation of the model sets a clear boundary with respect to the usefulness for investment decision making. The results indicate that allowing abatement via sCER permits has a negative impact on wind power investment for a set of assumptions standard in the current energy literature. This also implies that the value of the option to invest into a gas power plant increases by allowing sCER usage. The results showed that at the current low market prices for emission permits, allowing more baseline-credit-scheme credits with similar characteristics as the sCER, does change investment behavior significantly (Scenario 2) compared to the current 15% quota regime (Scenario 1).

Thus, if policymakers do allow abatement via baseline-credit-schemes, it is important that they ensure that the abatement does actually take place in the originating countries. Since these credits reduce the incentive to invest into renewable energy in developed countries and may therefore cause more pollution on a global scale, it must be ensured that the abatement in the originating country does take place. The CDM has been criticized for not ensuring this happens and our results confirm that this is an important issue to be addressed, considering the impact the CDM has on investment behavior in developed countries. The EU has built in a safeguard for this issue, requiring operators to retire one EUA permit if a sCER permit is used [12]. However, this implies that the abatement actually still does take

[12]"Subject to paragraph 3, during each period referred to in Article 11(2), Member States may allow operators to use CERs and ERUs from project activities in the Community scheme up to a percentage of the allocation of allowances to each installation, to be specified by each Member State in its national allocation plan for that period. This shall take place through the issue and

place in the EU in addition to the abatement in the originating country. Therefore, the CDM is more a tool to promote green energy investment in developing countries, rather than a mechanism to allow abatement to take place where it is cheapest.

Finally, policy makers should consider that allowing sCER requires them to subsidize renewable energy at a higher rate than without them. sCER make fossil fuels a more attractive energy option. If it is a political goal to increase the share of renewable energy, this renewable energy will consequently require higher subsidies. Since the costs of the subsidies are usually born by consumers and companies, this represents a social welfare factor worthwhile to consider.

3.6 Conclusion

In this paper a modeling framework was presented in order to answer two questions:

- What is the probability that in t years the value of the option to build a gas plant is larger than investing into a wind power plant under permit price uncertainty?
- What is the impact of being able to use permits originating from the Clean Development Mechanism on this probability?

These questions will become more important as carbon markets mature and more financial and risk-management tools become available over the next years. The maturing of the market will stem from two main influences: First of all, more obligatory cap-and-trade ETS will emerge world-wide moving actors further along the learning curve of what tools they need and how such markets operate. Secondly, more baseline-credit-schemes such as REDD are likely to emerge. Connecting those offset mechanisms with a variety of separate carbon markets worldwide, and evaluating the impact on renewable energy investment will be a major task for policy makers.

In our model we included the two main permit classes in the currently only obligatory cap-and-trade ETS world wide, the EU ETS. In the EU ETS energy producers can trade and buy emission permits that are allocated or auctioned by the EU and national governments (EUA), or use the flexible Kyoto mechanisms, a baseline-credit-schemes, to achieve the required emission reductions. We focused on the currently most influential permit class originating from the Clean Development Mechanisms (CDM), secondary Certified Emission Reductions (sCER). These are resold primary CER which are obtained by investing in projects in developing

immediate surrender of one allowance by the Member State in exchange for one CER or ERU held by the operator in the national registry of its Member State" - `http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:338:0018:0018:EN:PDF` countries that save emissions due to the investors involvement. Together, the EUA and sCER make up more than 95% of the EU ETS market. The permit prices follow stochastic processes which are taken as exogenous by a price taking firm. Both price processes evolve according to a geometric Brownian motion with a positive trend. The increments of the Wiener process of the two price-processes are positively correlated.

In order to answer the first question, we calculated the option value to invest into a gas power plant relative to the profits made by investing into a wind power plant. We simulated three different policy scenarios, comparing the gas power plant option value with the wind power plant, in order to answer our second question: First of all, a business-as-usual scenario in which regulation and the interdependence of the two permit classes are similar to current conditions. Secondly, a scenario in which more offset permits can be used in order fulfill abatement requirements. Finally, we considered a scenario in which new ETS markets emerge worldwide changing the correlation between the two Wiener processes. In nearly all scenarios we find a negative influence of sCER on the investment probability in wind power plants. The probability of investing in a wind power plant is modestly reduced in scenarios 1 and 3, while in scenario 2 the reduction is large. Our sensitivity analysis shows that the two energy types are relatively close in terms of cost competitiveness when taking into account the price development of permit prices over a longer period of time. Lower interest rates lead to a higher likelihood of investment into wind power. This is due to the effect that over time wind becomes relatively more profitable to gas as permit prices rise and a lower discount rate strengthens this effect. Increasing the volatility leads to a higher investment probability for gas power plants in later periods. This is due to the effect that the information value of waiting increases with higher volatility, rendering the option to wait to invest into a gas power plant more valuable. Finally, even when using the same trend value for both permits classes, the availability of sCER permits renders investment into gas power more likely. Since our model represents a best guess of the future development of permit prices based on previous results in the literature and the current political situation, it is the general direction and relative inter-scenario size of the effect which is the main result. We included a premium for wind power electricity to simulate a feed-in tariff like subsidy. The results showed that a substantial subsidy will still be necessary under current conditions for the coming years. Disallowing the usage of sCER permits could reduce the level of the subsidy.

In conclusion, allowing abatement via sCER permits has a negative effect on investment probability for uncertainty free wind power plants and a positive on the option value of gas power plants, given current modeling values for energy investments. Considering that other forms of renewable energy are even more expensive in their cost structures, this result implies a general negative effect of sCER on all renewable energy investments. This effect can contribute to locking the energy sector in a fossil fuel state since investment once undertaken is irreversible and long-lived, and might therefore requiring countervailing measures. This does not automatically imply that CO_2 emission levels are higher with the availability of sCER. Since the energy sector faces a maximum level of emissions in the EU, their availability may only change the composition of energy production, not the amount emissions as long as the limit is fully used. We also showed that changes in the economic environment, which can lead to changes in the standard parameter values used for energy investments, can have a significant impact on the likelihood of investing in renewables, due to their interplay effect on the long-term profitability of an energy type.

Several extensions of the model presented here are interesting for future research. First of all, since we only consider a price taking firm it would be interesting to look at a market in which the company can influence either the price of permits or the allocation by the government, thus endogenizing the price development of emission permits. Furthermore, one could consider a firm that can purchase sCER but can also directly invest into CDM projects, thereby obtaining pCER. Also, if data are available on new offset mechanisms, it will be interesting to see how they influence each other and the investment behavior. Finally, it would be interesting to look at the impact of offset mechanisms if a company already has a a portfolio of power plants.

Chapter 4

The Influence of Permit Price Uncertainty and Lobbying on Energy Investments

4.1 Introduction

The importance of environmental issues in the policy arena has changed substantially over the last decades. Issues such as acid rain, the depletion of the ozone layer and climate change have put environmental concerns high on the priority list of policy makers. Solutions to these issues range from market based approaches, voluntary agreements, to command-and-control approaches. Not surprisingly, these regulatory decision have affected especially industrial sectors (energy, oil, carmakers) and led to the formation of lobby groups who try to influence the political process in their favor. With the introduction of renewable energy support mechanisms especially in many European countries, renewable energy producers have also become an important lobbying force over the last decade, for example the European Wind Energy Association with over 700 members from 60 countries[1] . Furthermore, non-governmental organizations (NGO) have increasingly become involved in the political process, usually with opposing views to those of the industrial lobby.

Early political economy investigation of the impact of lobbying on political decision making focused on the losses caused by competing lobby groups (Becker, 1983, 1985). In their seminal work Grossman and Helpman (1994) present a model in which several groups make political contributions in order to influence trade policy. More recently, Conconi (2003) considered the impact of green lobbies on international trade. Furthermore, a literature related to lobbying and its effect on emission markets has evolved. Lai (2006) focuses on the impact of lobbying on the initial allocation of pollution rights. Lai (2008) investigates if auctioning, grandfathering or a hybrid instrument is chosen when environmental and industrial groups can influence the process. Hanley and Mackenzie (2010) consider a three stage model where firms have the opportunity to increase their own permit allocation and the aggregate permit allocation. Habla and Winkler (2013) introduce a model where governments first decide whether to become part of an international permit market and in the second stage about national permit allocations. In both stages lobby groups can influence the outcome.

A central element missing in the before mentioned literature is uncertainty. When considering the impact of uncertainty on investors in the electricity sector, where investments are usually irreversible, employing real options methodology is a viable approach. Compared to methodologically simpler approaches such as Net Present Value (NPV), a real options approach takes into account future realizations, allowing optimal timing of the investment decision. After the original development of financial options valuation by Black and Scholes (1973) and Merton (1973), their techniques were adopted for real-investments in the physical sense by Myers (1977).

[1] `http://www.ewea.org/about-us/`

Dixit and Pindyck (1994) and Trigeoris (1996) provide a good overview with numerous examples. Real options applications to the environmental and energy questions have been on the rise in recent years[2], but none have considered the impact of lobbying.

Attempting to bring the fields of real-option analysis and political economy closer, we address the following questions:

- What is the impact of lobbying for wind or gas power on the investment decision under permit price uncertainty?
- When is the option to lobby used?
- Is the wind or gas lobbying option used?

These questions are of relevance as large energy companies seem reluctant to invest large sums into renewable energy, despite a range of newly provided incentives, such as feed-in tariffs. Furthermore, large energy companies do not seem to engage in lobbying activity to enhance the profitability of renewables. We want to show if this behavior can be explained in an uncertainty framework where lobbying for fossil energy implies the reduction of permit price cost, and lobbying for wind implies a premium on the electricity price compared to fossil energy. Also, we want to get a sense of the magnitude of the incentives that are necessary to impact the investment behavior of large energy companies. The results we generate with our model are best interpreted as information for a government that wants to evaluate the effectiveness of its renewable policy while allowing lobbying for fossil energy, not as an indication of actual investment decisions of companies. A much more complex model including daily data and a range of other stochastic processes would be required to simulate this.

In order to answer these questions, we incorporate uncertainty in a simplified setting where an investor can choose between investing in a wind or a gas power plant over a fixed time horizon. Uncertainty stems from the stochastically evolving permit price which also affects the electricity price. The permit price follows a geometric Brownian Motion (gBM) with a positive trend. In the first year 40 gas power plants are installed, and each year one plant needs to be replaced. Simultaneously, the investor can choose to lobby the government in order to decrease the permit price for one period by a fixed percentage, or to receive a higher remuneration for wind energy. Lobbying expenses are irreversible once incurred and cannot be used for other purposes. The opportunity to spend money on lobbying efforts therefore represents

[2] See for example Insley (2003); Abadie and Chamorro (2006, 2008); Yang et al. (2008); Fuss et al. (2009, 2010); Abadie and Galarraga (2011). For a more elaborate overview we point the reader to Hieronymi and Schüller (2013).

a real-option to render gas or wind power plants more profitable in a certain period. By employing this approach the investor takes into consideration the complete time horizon when making his decision, which might lead to a postponement of lobbying efforts to later periods when the price is likely to be higher.

The rest of the paper is organized as follows: Section 2 provides some background information about the politics of lobbying on climate change issues. In Section 3 the model is described. Section 4 describes the data used in the model. In Section 5 we present and discuss the results of our model and perform a range of sensitivity checks. In section 6 we conclude.

4.2 Lobbying and the politics of climate change

The main interest groups involved in climate change policies in the European Union (EU) and the United States (US) are the democratic state, polluting industry and NGOs (Svendsen, 1999; Gullberg, 2008). Fredriksson et al. (2005) show that in more democratic states environmental policy is more stringent, but that a threshold needs to be reached before this effect plays a role. Furthermore, he shows that when this threshold has been passed, the number of NGOs active on environmental issues raises stringency as well. While NGOs have been able to exert more influence on the climate policy process (Gulbrandsen and Andresen, 2004), energy intensive companies and the polluting industries have considerably more resources to influence the process and are better organized (Gullberg, 2008; Wettestad, 2009). Large energy producers with high CO_2 levels are organized via EUR-ELECTRIC in the EU. A comprehensive overview of lobbying organizations for different industries can be found in Markussen and Svendsen (2005). In some cases environmentalists and industrialists cooperate, for example when pushing for wind energy subsidies (Brandt and Svendsen, 2004). However, usually they represent starkly contrasting views. A case study by Skodvin et al. (2010) shows how the option of introducing a large scale auctioning system, favored by NGOs over the grandfathering approach, was discarded due to lobbying by polluting industries. In some cases, even industrial lobby groups have differing goals. Helm (2010) looks at the British renewable and emissions policy, and also finds evidence of lobbying activity that influenced the policy making process in a way to be more industrial friendly.

Whereas some energy lobby groups favor a low CO_2 permit price, mostly carbon intensive producers that rely on coal energy, others favor a high permit price such as producers that own many gas and nuclear power plants. The reason for this apparently odd behavior by gas and nuclear power producers lies in the way rents accrue in the energy market with the introduction of CO_2 permits (Keppler and Cruciani, 2010). The electricity price at any point in time is set by the highest cost base load power plant, which is usually a emission intensive fossil fuel based plant. So called infra-marginal rents accrue when a high cost power plant is producing at the same time as a lower cost energy plant that can sell its electricity for the same price. In the past these infra-marginal rents compensated producers for the various types of production and dispatch risks. The distribution and significance of these infra-marginal rents has changed with the introduction of CO_2 permits. In most cases the permit price was fully passed on to the consumer, even though permits were allocated via grand-fathering. Carbon intensive producers were able to reap some extra profit, while relatively carbon free energy production from gas and nuclear power became significantly more profitable the higher the permit price (Keppler and Cruciani, 2010). These effects are also likely to occur when permits are fully auctioned, favoring low emission energy plants even further.

In the following model description we abstract from this situation and focus on the case when higher permit prices would actually represent a cost increase instead of an net increase in profit due to infra-marginal rents. Furthermore, we do not consider fossil fuel production competition due to already operating nuclear and coal plants, which lies at the core of the above described behavior. Instead, we investigate the incentive to invest into renewable energy as compared to fossil fuel power while lobbying can influence the profitability of either renewable or fossil fuels.

4.3 The Model

4.3.1 Profit function and investment option

In our model we look at an energy investor that represents the energy industry as a whole. We consider this as the appropriate modeling approach, since lobbying in disaggregated form on energy issues on a company by company level is usually not observed, as described in section 2. Furthermore, one company alone is not able to influence the permit price, therefore each single company is a price taker. However, when organized internationally with all the major companies part of such a lobbying organization, the permit price can be influenced. We abstract from cartel issues and do not consider tacit collusion and price manipulation. Instead, we consider the possibility of influencing the political process in order to reduce the emission permit price in order to render fossil energy investments more profitable, or to engage in lobby activity that leads to a higher electricity price for wind energy. Our model simulates a 40 year period. In every year a predetermined amount of existing infrastructure needs to be replaced. The investor can either choose to replace the existing infrastructure with a wind power or a gas power plant. Both types of investments are considered as irreversible. Companies have to comply with

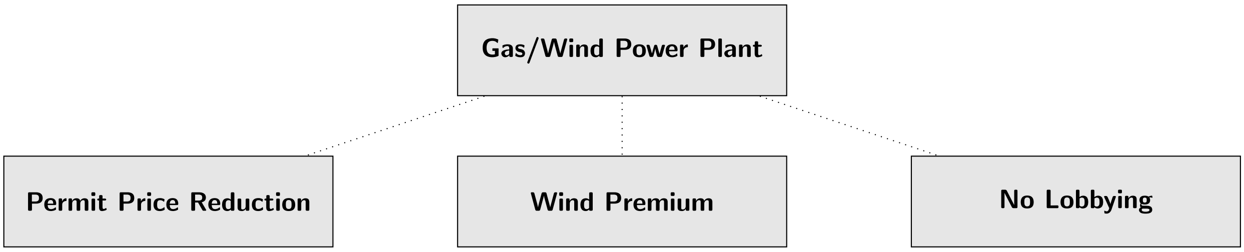

Figure 4.1: Investment/ Lobbying decision at time t

emission abatement requirements when investing into gas power plants, which is done by obtaining emission permits. Permits are not grandfathered but have to be purchased. An increase of the permit price triggers an electricity price increase. How much of the cost can be passed through is fixed at the beginning of the model.

The investor decides each period if he wants to invest into lobbying efforts which are costly and irreversible. By employing a real-options methodology the investor can postpone this investment taking future realizations into account. This increases the value of the lobbying options compared to an NPV approach. If lobbying is carried out the permit price is reduced by a fixed proportion $\in [0,1]$ or the electricity price received for energy from wind power plants is increased by a fixed amount. As a simplifying assumption permit price reductions or energy price increases due to lobbying are intertemporally unrelated. This means increases/reductions have to be renegotiated each period and there is no permanent effect. Both are set back to their respective prices without the influence of lobbying efforts at the end of a period. In Figure 4.1 the decision tree an investor faces each period is illustrated.

The motivation for the reduction of permit prices stems from the negotiations concerning the long-term CO_2 reduction target in the EU. The reduction target until 2020 has now been fixed at 20% compared to 1990 emissions levels, scraping an envisioned 30% reduction during recent negotiations. The long-term reduction goal until 2050 is still under discussion. As the overall cap for the ETS is decided by the reduction goal, lobbying on this issue is most closely related to our lobbying approach. If the reduction target can successfully be pushed down via lobbying, the permit price will decrease since the cap will be at a higher level. Concerning the wind energy premium, feed-in tariffs for renewable energy production are most closely related to our modeling approach. Feed-in tariffs pay producers of renewable energy a premium over the market price, usually fixed for a time period exceeding 10 years. These have become an important tool for the rapid development of a renewable energy capacity. The profit function is defined as follows:

Profit Function:

$$\pi(x_t, a_t, b_t, P_t^P) = q^e P^e w_t(b_t) - q^g(x_t)P^g - OC(x_t) - c(a_t) - l(b_t) - (1 - L(b_t))q^P(x_t)P_t^P \tag{4.3.1}$$

- x_t = State the system is currently in at time t; Gas plants and/or wind power plants operating.
- a_t = Energy investment chosen at point t; Gas plant or wind power plant.
- b_t Lobbying choice at point t; Gas or Wind lobbying or no lobbying.
- $w_t(b_t) \in [0, 30]$ Wind premium in period t.
- q_e, P_e = Quantity and price of electricity
- q_g, P_g = Quantity and price of gas
- OC = Operating and maintenance cost
- $c(a_t)$ = One-Time Investment cost depending on the action chosen
- $l(b_t)$ = One-Time lobbying cost
- $L(b_t) \in [0, 1]$ = Permit price reduction when lobbying for gas power is carried out
- q^P, P^P = Price and quantity of permits purchased

The time horizon of the model is 40 years. This time horizon has been chosen, since the average operating life-time of a gas power plant is about 30 years. The average operating life for an onshore wind power plant 25 years (IEA, 2010).

4.3.2 Permit Price-process

The price for emission permits follows a stochastic process. In accordance with results from the current literature that model the price development for European Emission Trading System permits (EU-ETS) (Yang et al., 2008; Fuss et al., 2008, 2009, 2010), we assume a geometric Brownian motion (GBM) with a 5% positive trend. This is essentially a political assumption. If the global goal is to limit the temperature increase caused by climate change to 2°C and permit markets are to play an important role in this, permit prices need to increase with a 5% trend. Otherwise the incentives to invest into carbon free forms of energy are insufficient. A second way of interpreting this modeling approach is that the 2°C goal with the necessary permit price increase represents the constant lobbying pressure by NGOs who work for a sustainable future.

The price process can then be described as follows: Let $(\Omega, \mathcal{F}, \mathbb{P})$ be a probability space and let W_t be a Wiener process with respect to a probability measure $\mathbb{P}$. Let $(\mathcal{F}_t)_t$ be the filtration generated by W_t. The price process P_t is described by the following equation:

$$\frac{dP_t}{P_t} = \mu dt + \sigma dW_t. \tag{4.3.2}$$

Hence P_t is a stochastic processes following a GBM. Here $P_{1,t}$ models the price process for EUA permits. μ is the drift parameter, σ the volatility parameter.

4.3.3 Bellman equation

The investor knows that emission permit prices evolve stochastically from a known starting value and therefore his problem is to determine the type of power plant he wants to invest in, and if he wants to invest into lobbying. In order to analyze this, we use the following Bellman equation solved recursively:

$$V_t(x_t, a_t, b_t, P_t^P) = \max_{a_t \in A_t(x_t), b_t \in B_t(x_t)} \{\pi(x_t, a_t, b_t, P_t^P) + e^{-r} E[V_{t+1}(x_{t+1}, P_{t+1}^P,)|P_t^P]\} \tag{4.3.3}$$

The first part of the equation is the immediate revenue stream a company obtains when investing into any of the two power plants or both at the same time. $A_t(x_t)$ is the set of feasible actions for a given state x_t and r. For example, if a gas plant has already been built $A_t(x_t)$ compromises the following actions: Build a gas power plant or a wind power plant. $B_t(x_t)$ stands for the possible lobbying actions: Wind premium, Permit price reduction, or no lobbying.

4.4 Data

4.4.1 Power Plant Data

In table 4.1 costs and CO_2 emissions of the different power plants are listed [3]. These are derived from "Projected Costs of Generating Electricity - 2010" (IEA, 2010) and current market data from the European Energy Exchange (EEX) (EEX, 2014). We compare a Combined Cylce Gas Turbine (CCGT) with an Onshore wind power plant. We follow Fuss et al. (2010) in assuming that operation & maintenance cost (O&M) as well as capital cost are deterministic. The load factor is the average

[3] All € values are converted into \$ values at an exchange rate of 1.35 \$/€.

Table 4.1: Electricity Generating Cost

	CCGT	Onshore Wind
Generation Capacity (MW)	480	45
Capital cost (overnight cost) (US$/kW)	1,068.00	2,348.00
Fuel Cost (US$ /MWh)	36,45	0
O&M (US$ /MWh)	4.48	21.92
CO_2 emissions (tCO_2/MWh)	0,33	0
Load Factor	85%	26%
Electricity price (US$)	81	81
Lifetime	30 years	25 years
Risk-adjusted rate	5%	5%

Source: IEA (2010); EEX (2014)

Table 4.1: Electricity Generating Cost

yearly usage of the full capacity of the power plant. Capital cost can be considered as overnight cost, which are the cost that would apply if the plant could be constructed overnight [4]. Using overnight costs for two different types of plants is a valid assumption, if the lead time does not differ substantially which is the case for wind and gas power (IEA, 2010; Kettunen et al., 2011). The electricity price is set at 60 € which lies approximately in between the medium-term baseload and peak market price (EEX, 2014) [5]. Concerning the deterministic gas price, long-term contracts are common for gas deliveries and current research estimates a stable mean-reverting trend for gas prices (Abadie and Chamorro, 2006; Boogert and de Jong, 2011). We do not consider technological progress since both power plants types are mature technologies which we assume to experience similar speed of technological improvement in the long-term, which leaves the overall investment decision unaffected. In the model, we consider the replacement of a 400 MW plant each year, which is roughly equal to the production capacity of one average gas power plant or 34 wind turbines. This implies that investment behavior is driven by the relative cost differences of these power plant types, not by the absolute investment size difference of an average gas power plant compared to a wind power plant

We assume a risk-adjusted rate of 5%. These values are in accordance with the literature on power investment (Kaplan, 2008; IEA, 2010; Kettunen et al., 2011). We use the same risk-adjusted rates for both power plant types, since the risk-

[4]"The overnight cost therefore excludes escalation in equipment, labor, and commodity prices that could occur during the time a plant is under construction. It also excludes the financing charges, often referred to as interest during construction (IDC), incurred while the plant is being built". (Kaplan, 2008, p.696)

[5]All data stemming from the EEX website, the electricity, gas and permit prices, were taken on 22. January 2014.

Table 4.2: Electricity and Price Process Data

	EU-ETS
Permit price trend	5%
Permit price volatility	20%
Permit starting price	8,8 US$
Electricity price pass through	30%
Wind power premium	27 US$

Table 4.2: Electricity and Price Process Data

adjusted rate only matters for operation and construction risk which is similar for both investment types.

4.4.2 Permit prices, electricty price and volatility

In table 4.2 the assumptions concerning the permit price process are listed[6]. We take current future prices of EU-ETS as a point of departure [7]. In accordance with current literature and modelling, we assume that the trend of the EU-ETS price is 5% and the volatility 20% (Fuss et al., 2010; Kettunen et al., 2011). We stress again that the 5% increase is a political assumption. If permit markets are to play a dominant role in offering the necessary incentives to limit to impact of climate change to 2°C by the end of the century, such a price increase will be necessary over time (Fuss et al., 2010). An alternative interpretation of this assumption is that this is the result of environmental pressure groups influencing the political process, thereby representing the counter weight to the industrial lobbying efforts. The high volatility found in the literature is due to the strong influence of political decision making on this market, which changes frequently. Currently, a set-aside is being debated in order to revive the dwindling CO_2 price, which would lead to a surge in permit prices[8]. Concerning the pass through rate for the EU-ETS, Fezzi and Bunn (2009) estimate that the pass through rate is around 30%, which we use as a baseline value. Renewable energy currently receives a range of support besides the indirect support of putting a price on CO_2 emission. We choose to incorporate these various form of support via a price premium for wind energy on the electricity price. Concerning the size of the subsidy, we took the German market as an example. In the German case, on-shore wind receives initially a very high premium, which can last up to 13 years (Wikipedia, 2014). The premium is then slowly reduced to match

[6]All € values are converted into $ values at an exchange rate of 1.35 $/€.
[7]EUA:6,52 €; Data from http://www.eex.com Date: 02.01.2013 converted into US$
[8]http://www.bloomberg.com/news/2012-03-15/eu-parliament-calls-for-emissions-permit-set-aside-option-1-.html

market prices. Based on the current feed-in tariff structure, on-shore wind energy then receives a premium of approximately 20€ per MWh. In the context of our lobbying model, this premium should be interpreted as amount that lobbying is able to convince policymakers of. Put differently, it stands symbolic for the receptiveness of the political system towards lobbying efforts.

4.4.3 Lobbying Cost

In the US expenditures related to lobbying efforts have to be made public and can be viewed on line[9]. For example, the lobbying expenditure of electric utilities was about US $ 145. million in 2011. Not included in this number are donations for political parties. We take this number as a indicative lower boundary for lobbying expenditures for both wind and gas lobbying and perform sensitivity checks with respect to different cost levels. Lobbying cost enter the model as a percentage of investment cost of a gas power plant, as described above. The investment cost of a gas power plant are based on the data provided above, totaling 427 Mill. $ [10].

Up until 2012 about 480 gas power plants were operating in Europe, with an average capacity of about 360 MW[11]. In 2010, 1600 gas plants[12] with a generating capacity of 1000 GW(Gigawatt)[13] were installed in the US, which is roughly 4 times as many plants with 3 times the generating capacity compared to Europe. We assume that the larger the market, the larger the lobbying expenses. Based on this we estimate that the lobbying expenditures in Europe should be around a fourth, of the US lobbying expenditures. This implies an indicative lower bound of around 36 Mill.$. Setting this in relation to the investment cost for a gas power plant, the lower bound for lobbying expenses is around 8.5% of the investment cost in our model. Since we only consider a model with 40 plants operating, this can be considered a conservative estimate since there are nine times as many plants operating in Europe, which implies that much more capacity needs to be replaced than in our model. Therefore, the actual lobbying expenditure per power plant is probably smaller.

[9] http://www.opensecrets.org/lobby/

[10] 400 MW * 1000 (KW conversion)* 1068 $ (overnight cost)*0.85 (capacity factor) = 427 Mill. US

[11] http://www.ecoprog.com/en/publications/energy-industry/gas-power-plants.htm

[12] http://www.eia.gov/electricity/annual/pdf/table5.1.pdf

[13] http://www.eia.gov/electricity/annual/pdf/tablees1.pdf

4.5 Results

4.5.1 Results

In this section we report the results of our model. Each scenario is run 2,000 times. The first graph for each scenario shows the number of gas plants that are installed in a certain year. The model starts with 40 gas plants and 1 plant has to be replaced every year. Thus, if less than 40 plants are gas plants the remaining ones are wind power based. The red line shows the number of gas plants installed when companies can lobby, while the blue line shows the case when no lobbying is possible.

First of all, we consider the effect of allowing lobbying for wind as compared to the case where only gas lobbying can take place. Unless reported differently, certain values remain the same for all scenarios in this section and won't be reported again: The volatility rate of the permit price was set at 20%, the emissions price trend at 5%, the pass through rate at 30% and the interest rate at 5%. In figure 4.2 the results for the case where only gas lobbying is allowed are reported. When only gas lobbying is allowed, gas plants are are replaced by gas plants and only towards the end of the time horizon wind investment becomes a possible choice, as can be seen in figure 4.3 where. In figure 4.4 we report the lobbying activity. No gas lobbying activity is carried out over the whole time horizon. The potential reduction in the permit price does not seem sufficient in order to justify the expenses which have to be incurred for lobbying.

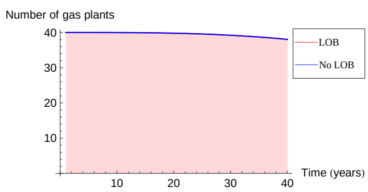

Figure 4.2: Gas Plant Investment
No wind premium scenario

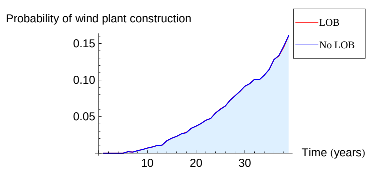

Figure 4.3: Investment probability wind
No wind premium scenario

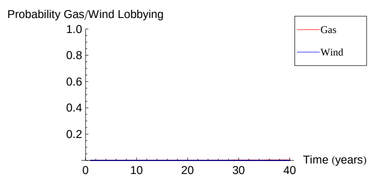

Figure 4.4: Lobbying Probability
No wind premium scenario

In figures 4.5-4.8 we report the results for the case when both types of lobbying are allowed, and the wind premium is equal to 20 €. As can be seen in figure 4.5, wind power becomes the replacement choice after a few years and by year 40 more than a quarter of the energy production is carried out by wind energy. In figure 4.6 we report the investment probability for wind. It quickly rises and reaches more than 50% by the end of the time horizon. The probability of wind investment with the opportunity to lobby is significantly higher than the without lobbying, as indicated by the blue area in figure 4.5. Wind lobbying becomes a profitable choice and lobbying activity rises quickly, reaching 70% towards the end of the time horizon. Gas lobbying is not carried out at all in this scenario. In figure 4.8 the CO_2 price is depicted. The price is the same with or without lobbying, since no gas lobbying is carried out which would impact the permit price. The increase over time stems from the price process by which the permit prices are driven, which we described in section 4.2.

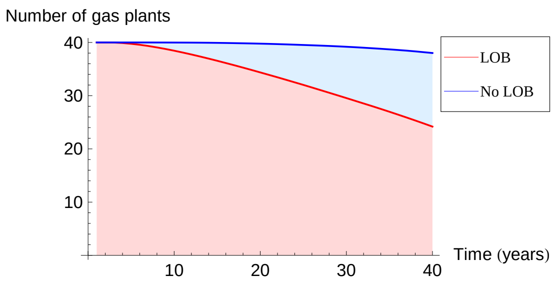

Figure 4.5: Gas Plant Investment
Wind premium scenario

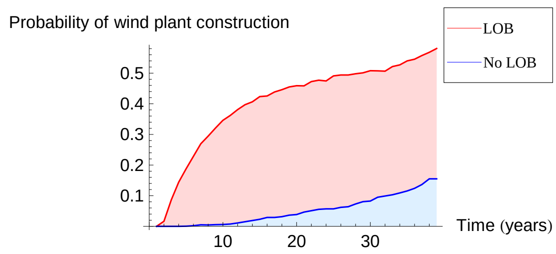

Figure 4.6: Investment probability wind
Wind premium scenario

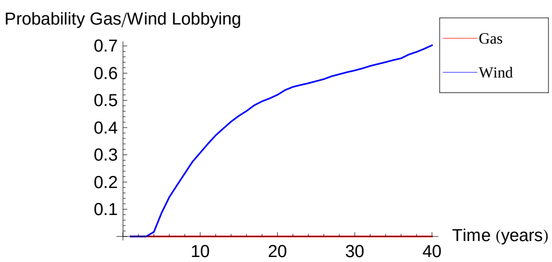

Figure 4.7: Lobbying Probability
Wind premium scenario

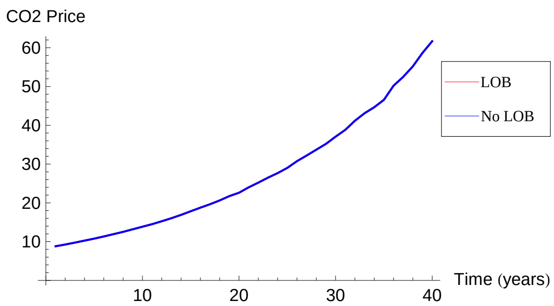

Figure 4.8: CO_2 Price
Wind premium scenario

In figures 4.9-4.11 we report the results of a scenario which shows the necessary level of incentives in order to stimulate gas lobbying. Lobbying cost are 10% of gas power investment cost, the permit price reduction of successful gas lobbying is 75%, and the wind power premium is 10€. In this scenario, gas power investment remains the dominant choice since only at the end of the time horizon wind power investment does take place. More importantly, lobbying for gas power dominates wind power lobbying over the whole time period (Figure 4.10), which leads to a significant drop in the CO_2 price over time (Figure 4.11).

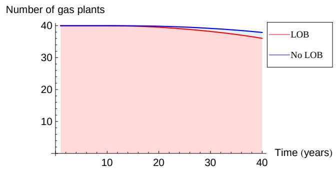

Figure 4.9: Gas Plant Investment
Gas lobbying scenario

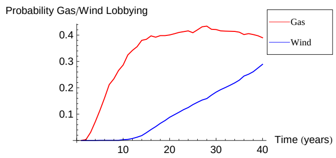

Figure 4.10: Lobbying Probability
Gas lobbying scenario

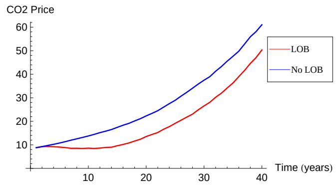

Figure 4.11: CO_2 price
Gas lobbying scenario

Finally, we present two scenarios to make a comparison between the European Energy Markets with its feed-in tariffs and the US system with no CO_2 markets or substantial renewable subsidies. The main renewable energy support mechanism in the US are production tax credits, which have not been considered as reliable mainly due to a uncertain renewal policy (Lewis and Wiser, 2007; Barradale, 2010). In both scenarios, gas power lobbying is able to reduce the permit price by 100%. This implies that gas power lobbying is able to completely offset the cost of CO_2 emissions, or put differently, it can completely stop the establishment of an effective permit market. The first scenario with 100% gas power lobbying effectiveness and no renewable subsidy is depicted in Figures 4.12-4.14. In the second scenario, we also allow for a wind power premium of 20€ in order to show the difference such a mechanism would cause. The results of this scenario are shown in Figures 4.15-4.17.

Without a renewable subsidy and a 100% effectiveness of gas power lobbying, nearly no renewable energy infrastructure is installed after a 40 year time period (Figure 4.12). Furthermore, after the CO_2 price reaches approximately 10€ gas lobbying activity quickly starts developing, reaching a probability of 0.4 by the end of the time period (Figure 4.13). This heavily influences the CO_2 price, which remains at a level of around 10€ until year 30 when it starts to increase again (Figure 4.14).

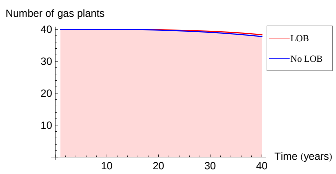

Figure 4.12: Gas Plant Investment
US scenario no subsidy

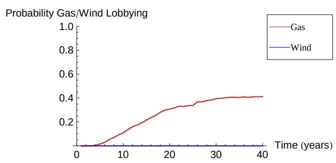

Figure 4.13: Lobbying Probability
US scenario no subsidy

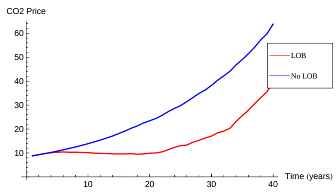

Figure 4.14: CO_2 price
US scenario no subsidy

When introducing a renewable subsidy of 20€, even a 100% permit price reduction is not sufficient to render gas power more profitable than wind energy. At the end of the time period about quarter of the energy production stems from renewable energy (Figure 4.15). This is very similar to the results obtained in the "Wind Premium" scenario, where gas power lobbying only had a 20% effectiveness (Figure 4.5). In comparison to this scenario some gas lobbying activity is carried out, even though at a relatively low level compared to wind power lobbying (Figure 4.16). Therefore, the CO_2 price with lobbying differs minimally from the one without (Figure 4.17).

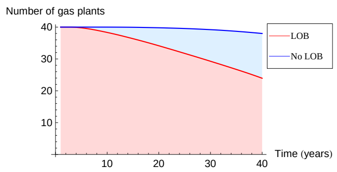

Figure 4.15: Gas Plant Investment
US scenario with subsidy

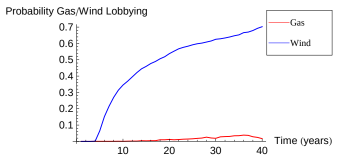

Figure 4.16: Lobbying Probability
US scenario with subsidy

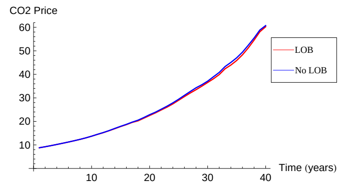

Figure 4.17: CO_2 price
US scenario with subsidy

4.5.2 Sensitivity checks

In this section we report a range of sensitivity checks with respect to the interest rate, volatility, gas price, trend of the price process, wind energy premium, and the potential permit price reduction due to the lobbying effort. As a baseline comparison we choose the following values: Lobbying cost are 20% of gas plant investment cost, the permit price reduction is 20%, and the wind power premium is 20€. In the following sets of graphs we lower the value we test for sensitivity to the left, and increase it to the right.

The impact from changing the interest rates from 1%-5%-9% on gas investment can be seen in figures 4.18-4.20, the impact on the lobbying effort in figures 4.21-4.23. A 1% interest rate leads to a complete replacement of the original 40 gas power plants by the end of the time horizon with lobbying activity. This is due to the fact that a low interest rate favors wind power, since this type of power generation becomes more profitable relative the gas power the higher the permit price. Since the price process follows a gBM with a positive trend, the effect increases the further we move along in time. Consequently, at a 9% interest rate there are only few wind power plants installed by the end of the time horizon.

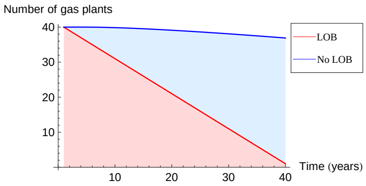

Figure 4.18: Interest Rate 1%

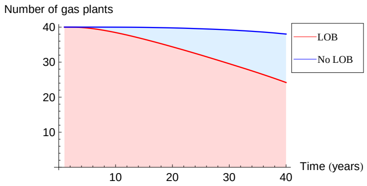

Figure 4.19: Interest Rate 5%

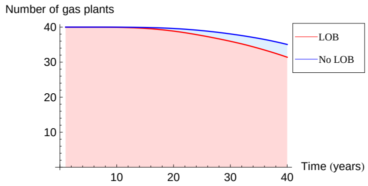

Figure 4.20: Interest Rate 9%

Concerning lobbying behavior, a similar pattern compared to previous results can be observed. When wind power is very profitable and installed early on in the model, it pays to invest into lobbying efforts for wind energy (Interest Rate 1%, Figure 4.21). When gas power is more profitable wind power lobbying still dominates gas lobbying (Interest Rate 9%, Figure 4.23), but only leads to wind power as the investment choice by the end of the time horizon.

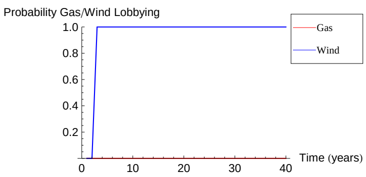

Figure 4.21: Interest Rate 1%

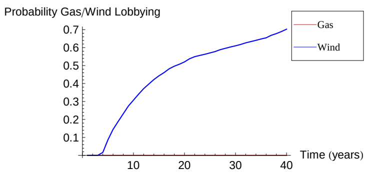

Figure 4.22: Interest Rate 3%

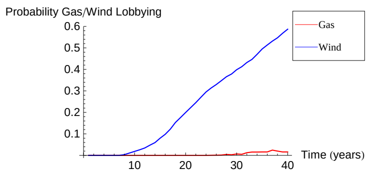

Figure 4.23: Interest Rate 5%

In figures 4.24-4.26 we show the results for differing wind premium values on the number of gas power plants installed. The difference caused by decreasing/increasing the wind premiums is substantial with respect to the amount of installed renewable capacity by the end of the time horizon. Whereas a premium of 10€ leads to an installed capacity of less than 10%, a 20€ premium already leads to a quarter of installed renewable capacity, and a 30€ premium leads to 100% of renewable capacity in year 40.

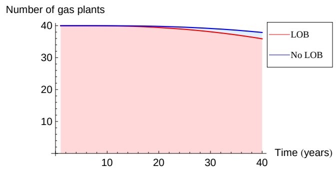

Figure 4.24: Gas Plant Investment
(10 €Wind Premium)

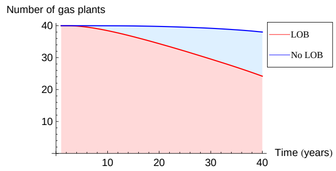

Figure 4.25: Gas Plant Investment
(20 €Wind Premium)

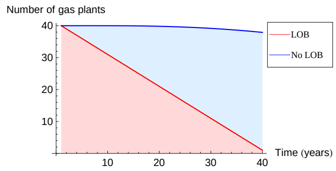

Figure 4.26: Gas Plant Investment
(30 €Wind Premium)

Figures 4.27-4.29 show the lobbying activity in these scenarios. Whereas a premium of 10€ leads only to a wind lobbying probability of 30% by the end of the time horizon, a premium of 30€ increases this probability to one over nearly the entire time horizon. Lobbying in order to increase the profitability of gas power plants becomes entirely unprofitable in all scenarios.

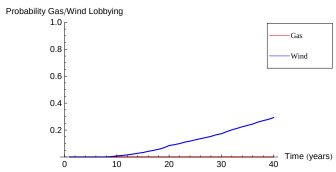

Figure 4.27: Lobbying Probability
(10 €Wind Premium)

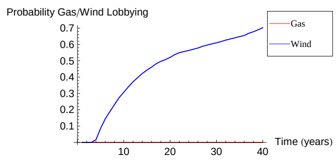

Figure 4.28: Lobbying Probability
(20 €Wind Premium)

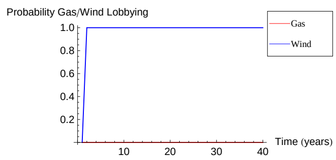

Figure 4.29: Lobbying Probability
(30 €Wind Premium)

In figures 4.30-4.32 we report the impact of changing the permit price reduction achieved by lobbying. We only report the lobbying probability, since the investment probability only changes marginally with respect to the baseline scenario. The figures show that when an investor can receive a 20€ premium for wind energy or a 0.1-03 permit price reduction, an investor rarely chooses to lobby for fossil energy. Wind power lobbying behavior does not change substantially when varying the permit reduction rate.

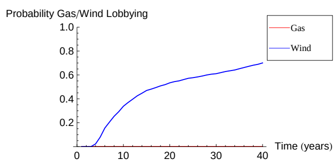

Figure 4.30: Lobbying Probability
(Permit price reduction 10%)

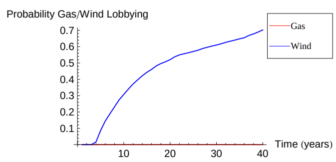

Figure 4.31: Lobbying Probability
(Permit price reduction 20%)

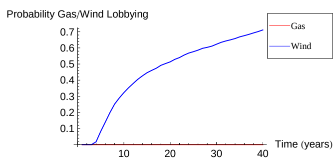

Figure 4.32: Lobbying Probability
(Permit price reduction 30%)

In Figures 4.33-4.38 we report the effect of changing the volatility on investment and lobbying behavior. The higher the volatility the more gas power plants are installed even with a 20 € premium for wind energy. In the context of our model a high volatility implies a higher chance in later periods that the emission price can be very low, rendering gas power investment more likely. Lobbying behavior (Figures 4.36-4.38) does not change significantly compared to previous results.

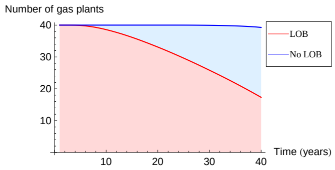

Figure 4.33: Gas power Investment
(Volatility 10%)

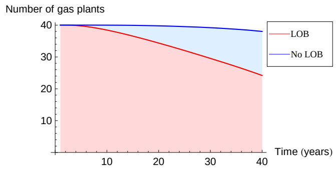

Figure 4.34: Gas power Investment
(Volatility 20%)

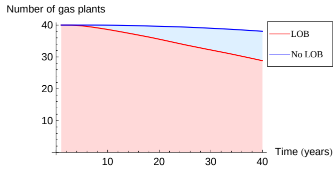

Figure 4.35: Gas power Investment
(Volatility 30%)

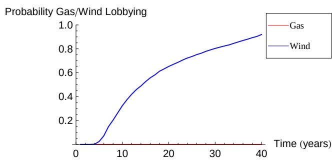

Figure 4.36: Lobbying Probability
(Volatility 10%)

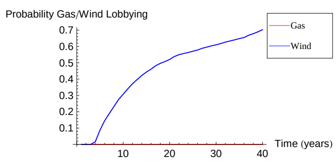

Figure 4.37: Lobbying Probability
(Volatility 20%)

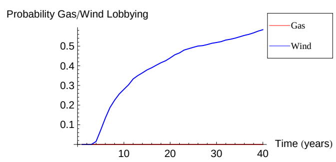

Figure 4.38: Lobbying Probability
(Volatility 30%)

In figures 4.39-4.41 we report the impact of changing the gas price on investment behavior. Figures 4.42-4.44 show the effect on lobbying behavior. Changing the gas price to 10€ renders gas power very profitable and leads to nearly no renewable energy installed by the end of the time period, despite a 20€ wind premium (Figure 4.39). A 50€ gas price has the opposite effect, nearly all of the installed capacity is wind energy based by the end of the time horizon (Figure 4.35). These results show that he gas price has an impact on the results of our model, however changing the values to 10€ or 50€ is arguably a tremendous price change which is usually not observed in the gas market, at least in the short to medium-term.

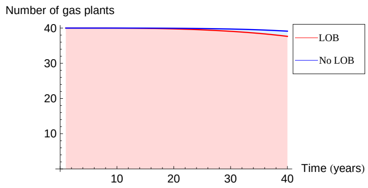

Figure 4.39: Gas power Investment
(Gas Price 10€)

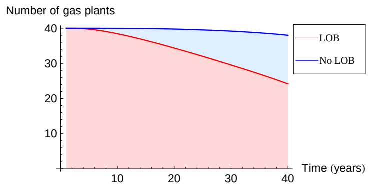

Figure 4.40: Gas power Investment
(Gas Price 27€)

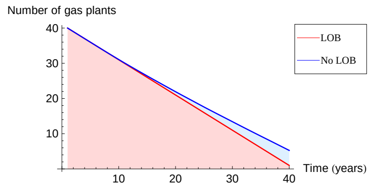

Figure 4.41: Gas power Investment
(Gas Price 50€)

Concerning lobbying behavior, a low gas price leads to a very low level of lobbying activity for both wind and gas. A high gas price renders wind power lobbying very lucrative, since a large quantity of wind power is quickly installed which renders the already more lucrative wind lobbying relative to gas lobbying even more profitable.

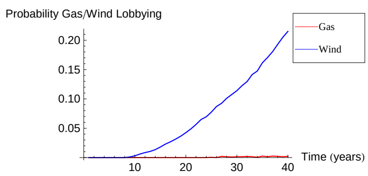

Figure 4.42: Lobbying Probability
(Gas Price 10€)

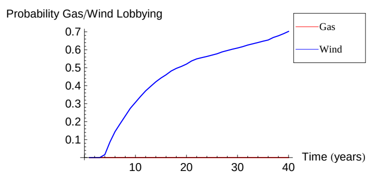

Figure 4.43: Lobbying Probability
(Gas Price 27€)

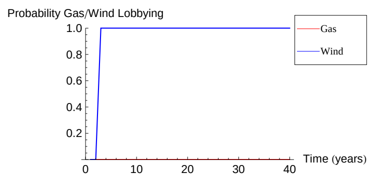

Figure 4.44: Lobbying Probability
(Gas Price 50€)

We also tested for a range of values for the price trend (1%, 5%, 10%), and the lobbying cost (10%, 20%, 30%). None of the changes resulted in a significant deviation from previous results concerning investment and lobbying behavior.

4.5.3 Discussion

The results we have presented so far indicate that wind lobbying is the preferred choice, as CO_2 prices seem to be too low to warrant lobbying for permit price reductions. However, the size of the wind power premium needs to be substantial in order to change the energy mix by the end of our time horizon. A premium of

20€, a third of the starting electricity price in €, leads to 25% of installed wind energy capacity, a 30€ premium to 100%. Thus, at current permit prices, wind lobbying needs to achieve a substantial effect in order to change from a fossil to a renewable energy infrastructure. It is important note that our models start with 40 installed gas power plants. Therefore, wind lobbying has to be significantly more profitable per power plant, in order to change the energy infrastructure, as lobbying makes each power plant more profitable. We also reported the level of permit price reduction and lobbying cost necessary in order to provide sufficient incentives for energy producers to lobby for a permit price reduction. In a scenario with a 10€ wind energy premium, lobbying cost of 10% relative to gas power investment and a permit price reduction of 75% lead to significant lobbying behavior towards permit price reductions. If such a level is reasonable for the effect of lobbying is certainly open to debate, but this gives an indication of the necessary effect that lobbying for fossil fuels would need to have in order to be profitable. Furthermore, we presented two scenarios in order to make a comparison between the US energy market with no CO_2 market and renewable subsidies and the European market. In order to emulate the US market within our model, we changed the permit reduction to 100% and removed the renewable energy lobbying option. In such a model, nearly no renewable energy will be installed by the end of the time horizon, gas lobbying becomes profitable when the CO_2 price reaches approximately 10€, and the CO_2 price stays around this level over the remaining time period due to lobbying activity. We then allowed for renewable lobbying which yielded a 20€ premium if successful, and found that even though gas lobbying took place with a certain probability and reduced the permit price towards the end of the time horizon, more than a fourth of the installed energy generating capacity was renewable. This implies that a significant renewable subsidy can overcome strong gas lobbying measures, at currently low CO_2 prices.

Concerning the sensitivity tests, we found that the interest rate, the wind premium, the volatility and gas price have the largest effect on our results. The interest rate is the most significant one as it affects the long-term investment prospects to a large degree. This implies that policymakers must be well-informed concerning the interest rate in an investment environment, if they want to judge the impact of policy changes. Another factor that is mostly influenced by policymakers is the volatility rate of permit prices. Permit markets are still strongly dependent on political decisions and therefore policymakers have a great level of influence on the volatility rate. Considering the effect policy changes has on volatility is therefore an important task.

Even though we only take a partial equilibrium perspective focusing on the profitability of companies leaving social welfare consideration aside, it is worth to analyze the rough magnitude of cost that the different scenarios imply. When only gas power lobbying is possible, the social planner suffers from a reduced revenue since the CO_2 price can be depressed which leads to lower permit auction income. Allowing for wind power lobbying renders gas lobbying unprofitable in most scenarios. Therefore, these permit auction cost vanish. However, the cost to society for the wind power subsidy and the higher cost for installing the considerably more expensive energy type might be substantial. Assuming that there is no global carbon market, renewable capacity installed in one region of the world does not imply overall lower CO_2 emissions due to carbon leakage issues. Avoided damages due to a reduced externality level would then not factor in. One should also consider the potentially lower fuel cost as less fossil energy is consumed, which increases the incentive for fossil fuel investment again. In conclusion, providing a wind power premium may entail substantial economic cost for society as a whole. Policy makers will have to decide if the benefits of renewable energy production, less CO_2 emissions at least in individual countries, a lower long-term energy price as production cost decrease, and jobs related to renewable energy production are worth the cost.

4.6 Conclusion

In this paper we presented a modeling framework to answer the following questions:

- What is the impact of lobbying for wind or gas power on the investment decision under permit price uncertainty?
- When is the option to lobby used?
- Is the wind or gas lobbying option used?

We incorporate uncertainty in a setting where an investor chooses between replacing a pre-determined generating capacity with either wind or gas power. Furthermore, he can choose to undertake lobbying efforts in order to influence the government to reduce the price of CO_2 emission permits, or to receive a energy price premium for wind power for one period. Whereas the investor has to build either one of the power plant types, he can defer lobbying efforts. Therefore, the value of lobbying is calculated as a put option in a real-options framework. The price of emission permits develops according to a geometric Brownian Motion (gBM) with a positive trend. Concerning lobbying efforts, the effectiveness of lobbying is fixed at the beginning of each scenario, in terms of a percentage price reduction for permits, or a fixed premium for wind energy. We interpret these values as the pliability of the government towards lobbying efforts. Values for construction related cost, energy production cost, and efficiency levels were taken from the literature.

We find that lobbying for permit price reductions at the currently low CO_2 price level is only profitable if the potential reduction is very large (75-100%) and the wind power premium is small (10€). Even a 5% emission price trend and 20% volatility, leading to a permit price of 40€ in year 40, are by itself not sufficient to increase renewable investment. If the wind power premium is 20€, about a quarter of the installed energy stems from wind by the end of our 40 year time period, rising to 100% for a premium of 30€. Furthermore, wind lobbying activity dominates any gas lobbying activity in such a scenario. The effect of wind lobbying is also substantial, in that the difference between a wind lobbying and no lobbying scenario in terms of investment probability into a wind power plant is up to 100%. We also considered a scenario emulating the situation in the US market with no CO_2 market and no effective renewable support tool. In this scenario we allowed for a 100% effectiveness of gas lobbying, implying that lobbying can completely stop the operation of a CO_2 market. We found that in such a scenario the amount of renewable energy is negligible by the end of the time period. Furthermore, gas lobbying activity still only becomes profitable when the CO_2 price reaches a level of around 10€. Once this threshold has been reached, lobbying activity is carried out frequently and keeps the CO_2 price at a level of 10€ until the last ten years when it stars increasing again. When introducing a wind energy premium of 20€ into such a system, a 25% renewable share in the energy mix can be reached. We performed a range of sensitivity checks with respect to the interest rate, volatility, trend of permit prices, gas price, the cost of lobbying, and effectiveness of lobbying. The interest rate plays a crucial role since a higher interest rate discounts the future more, and leads to a less favorable investment environment for wind power since this power type becomes more profitable over time relative to gas power. A lower interest rate has the opposite effect. The volatility also impacted the results in a significant fashion since a higher volatility may lead to low permit prices in later periods, rendering gas power more profitable. Changing the price of gas also has a significant impact on the investment decisions, however the changes need to be substantial. Such rapid and large changes of the gas price are rather unlikely in the foreseeable future.

Even though our model is a partial equilibrium analysis we gave an indication of the social welfare cost attached to the different scenarios. Under the assumption that a 5% permit price trend adequately captures the value of the negative environmental externality caused by CO_2 emissions, allowing for either type of lobbying implies a welfare loss. The scenarios clearly showed that a 5% trend coupled with currently low permit prices is not sufficient in order to induce investment into renewable energy. With the introduction of a feed-in tariff like support mechanism for wind power, the amount of renewable energy increased substantially. This support, however, comes at a cost. In addition to the cost for the subsidy, wind power is the more expensive energy type leading to higher cost for society. Furthermore, costly wind lobbying activity becomes profitable implying further cost. Without a global emission market carbon leakage can become an issue. Increased high cost renewable production in one part of the world may cause energy intensive production to move elsewhere or even increase incentives to use fossil resources via reduced market prices due to less consumption from renewable intensive countries.

The quantitative results of our model should be treated with care, since the 5% trend is the current best guess of what a future permit might like look like. The same argument applies to the lobbying cost. We performed sensitivity checks for both values in order to show how strongly these parameters affect the outcome. We also showed that the interest rate plays an important role, which also depends on market forces which cannot be predicted. Therefore, it is the general direction and relative size our results indicate which are the main result of our study, not specific year for year values. We have abstracted from cartel and oligopoly issues which certainly play a role in the permit market. Also, a thorough general equilibrium welfare analysis of the implied social costs are beyond the scope of our study. Addressing these issues is left for future research.

Chapter 5

Come Dine with Me: a Game-Theoretic Analysis

5.1 Introduction

Since its first broadcasting in 2005, the British TV-Show *Come Dine with Me* gained great popularity and is well established by now. Today, identical or very similar formats of the show are televised in 32 countries world-wide,[1] and often reach a quite remarkable number of viewers, as for example in Germany, Turkey and Israel.[2] In this show, four or five amateur chefs take turns in cooking and hosting a dinner party for each other during the course of a week. All contestants have to announce their menu before the first dinner, and cannot change it afterwards. After each dinner night the performance of the chef is evaluated by his contenders on a scale from 0 to 10, with 10 representing the highest score. The individual evaluations remain undisclosed until the show is eventually broadcast (several weeks or months later). The contestant with the highest cumulative score is the winner and obtains the cash prize of £1,000. If several contestants receive the same score the prize is split equally among those. Irrespective of the outcome of the contest, every contestant receives the same fixed amount to cover cooking and travelling expenses.

Although *Come Dine with Me* is a very popular TV-format, there are only few studies that investigate the strategic and behavioural aspects of this show. Notable exceptions are Haigner et al. (2010) who consider sequential position effects in the German version. These authors find that a negative position effect exists for the first competitor. Moreover, Ahmed (2011) compares the means of points given in the Swedish version of the show, and finds no significant differences between voting behaviour of men and women. While there is apparently little research on *Come Dine with Me*, there is a small literature on other TV-formats exploring these shows from a behavioural point of view: see, for example, Bennett and Hickman (1993); Berk et al. (1996); Anwar (2012); Page and Page (2010); van den Assem et al. (2011). Yet, similar game shows, such as *Shopping Queen Four weddings*, or *Big Brother* have not been investigated in a rigorous economic fashion either. The setting of *Shopping Queen* and *Four weddings* are closely related to *Come Dine with Me*: contestants rate each other's outfit or wedding during the course of a week, ratings remain concealed during the show and the winner receives a grand prize. Also, *Big Brother* is similar to *Come Dine with Me* as contestants' voting behaviour is anonymous for the other contestants but public to the television viewer. Furthermore, contestants may vote each other out of the game, and the winner is paid a cash prize at the end of the show.

The specific (strategic) structure of these shows can also be found in economic

[1]For example, the German format is called *Das perfekte Dinner* (since March 2006); the French, *Un Dîner Presque Parfait* (since February 2008); the Turkish, *Yemekteyiz* (since October 2008) etc.

[2]See, for example, http://en.wikipedia.org/wiki/Come_Dine_with_Me.

life: peer review evaluation systems (peer assessments), in particular peer ratings and peer rankings, in firms are a fine example. In these systems, employees mutually evaluate the performance of co-workers within the same department or division. The evaluations remain anonymous, but the results are usually used to measure the overall performance of an employee determining bonus payments or promotion. Thus, a multifaceted task is evaluated by peers, and the resulting aggregate evaluation determines monetary and/or professional success.

Due to the observed relevance of mutual evaluation games, we believe this kind of setting to be both practically relevant and theoretically interesting. In view of the sparse economic literature on this type of a setting, we explore the game-theoretic structure of mutual evaluation games, contrast the theoretical results with actual behaviour in *Come Dine with Me*, finally provide potential explanations why contestants submit evaluation profiles in accordance with game theoretic predictions.

As a first, though preliminary step, we argue why *Come Dine with Me* (and similar set-ups) may be identified as simultaneous, aggregative, n-player strategic games with $n-1$ dimensional strategy sets, and then intuitively explain a player's resulting incentive structure. Since individual evaluations remain undisclosed until the show is broadcast, participants do not know the evaluations received by antecedent chefs, and can thus not condition their evaluations on past voting behaviour of their competitors. With this lack of information, evaluations are made as if they had been chosen simultaneously. For this reason, we may interpret the choice of mutual evaluations as a strategic game played simultaneously by five players (contestants) each of which selects a score vector of length four with elements between 0 and 10, representing the respective evaluations of the other players. Then, since for each player the chances of winning are increasing in his own total score but decreasing in the total score of his contenders, the payoff of a player is non-increasing in the evaluations attributed to either of his competitors. Consequently, it is not in a player's interest to award some other player some positive score.

Thus, if contestants are solely interested in their own payoff without any fairness considerations or social preferences, one would expect contestants to rate each other with zero scores, as this would not only serve to minimize the chances of winning for the other contestants, but can also be achieved at zero (pecuniary) cost for the evaluating player. Furthermore, the evaluator does not have to fear punishment from his peers, since his voting behaviour is unobservable while the voting process continues, but is observable by the public upon broadcasting later. However, although there is neither the possibility of punishment nor even of identification during the game, zero evaluations are very rarely observed in the show. For this reason we have to look for possible explanations for non-zero evaluations awarded by participants in actual contests.

It is worthwhile to emphasise that we exclusively focus on the evaluation part of the show, taking the menu setting strategy as exogenous. This restriction of the strategy space seems to be appropriate as the menu has to be chosen in advance, in a situation of complete ignorance of the other contestants and the order of cooking, and without any commitment for the subsequent evaluation game. Also, the selection of menus requires the formulation of believes about the other competitors' tastes rendering the complete menu-selection-evaluation game to be a Bayesian game of a rather complex type. Since the subsequent *evaluation game* can strategically and chronologically be separated from the menu-selection decisions, the menu choices are disregarded here—and the pure *evaluation game* is the object of our analysis.

Correspondingly, this paper serves a threefold task. Firstly, we define a class of games, the class of *mutual evaluation games (MEG)*, and show that *Come Dine with Me* belongs to this class. Secondly, we explore the Nash equilibria of this class of games, and demonstrate that any MEG, and therefore *Come Dine with Me* in particular, has a unique Nash equilibrium in weakly dominant strategies where each player chooses an evaluation vector with all elements equal to the lowest possible evaluation level, which equals zero in the case of *Come Dine with Me*. That is, in this equilibrium all players evaluate all other players with zero scores, and we therefore refer to this equilibrium as the *zero equilibrium* henceforth. In addition, any MEG has numerous other (weak) Nash equilibria with non-zero evaluation profiles.

Due to the apparently salient features of the *zero equilibrium*—an equilibrium in (weakly) dominant strategies and choices of polar strategies—it may be regarded as highly appealing, standing out against any other equilibrium. Yet, in actual shows contestants typically do neither play the *zero equilibrium*, nor do they end up in any other Nash equilibrium. Consequently, even though the *zero equilibrium* has apparently appealing features, and is thus a canonical candidate for a strategy-tuple to be played, contestant do not choose to follow this strategy. Accordingly, we discuss possible explanations for this phenomenon, which may be attributed to social or behavioural aspects. Also, our discussion points upon potential directions for future research on contestants' actual behaviour in TV shows, or more broadly, on the behaviour in publicly observed games of the MEG class.

The rest of the paper is structured as follows. In Section 5.2 we define the MEG class and formalise the show *Come Dine with Me* as such a strategic game. In Section 5.3 we characterise the Nash equilibria of a MEG, and in particular of *Come Dine with Me*. Subsequently, in Section 5.4 we describe observed behaviour of contestants in actual shows and then provide possible explanations for why contestants fail to achieve some Nash equilibrium. Finally, we provide some concluding remarks in Section 5.5.

5.2 The Model

In this section we formally introduce a class of strategic games called *mutual evaluation games (MEG)*, and then show that the game *Come Dine with Me* belongs to this class. Also, we argue that a MEG is a special type of an aggregative game.

We use the following notation. $N := \{1, 2, \ldots, n\}$ denotes the set of players. (For *Come Dine with Me* we have $n = 5$.) In this game, each player assigns to each other player an evaluation or score, represented by a natural number between 0 and k (for *Come Dine with Me* k equals 10).[3] However, a player may not evaluate herself, which is formally captured by requiring player i to assign to herself the minimum evaluation level, *i. e.* a zero score. Accordingly, the strategy set of player i, $i \in N$ is given by

$$S^i := \{\mathbf{s} \,|\, \mathbf{s} = (s_1, \ldots, s_n)^\mathsf{T},\ s_j \in \mathbb{N}_{(k)} \text{ for } j \neq i, \text{ and } s_i = 0\},$$

where $\mathbb{N}_{(k)} := \{0, 1, \ldots, k\}$ represents the set of natural numbers up to k, $k \in \mathbb{N}$. Note carefully that a strategy (or action) of each player is not a scalar but an n-dimensional vector: a strategy $\mathbf{s}^i$ of player i consists of n evaluations $s^i_j \in \mathbb{N}_{(k)}$, one for each player $j \in N$, including the (notional) self-evaluation $s^i_i \equiv 0$.

While $\mathbf{s}^i$ denotes some n-dimensional strategy of player i, we write $\mathbf{S} := (\mathbf{s}^1, \ldots, \mathbf{s}^n)$ for the n-tuple of n-dimensional strategies, so that $\mathbf{S}$ may be identified with the matrix

$$\mathbf{S} = (\mathbf{s}^1, \ldots, \mathbf{s}^n) = \begin{pmatrix} s^1_1 & \cdots & s^n_1 \\ \vdots & & \vdots \\ s^1_n & \cdots & s^n_n \end{pmatrix},$$

where all diagonal elements of $\mathbf{S}$ equal zero, *i. e.*, $s^i_i = 0, \forall i \in N$. Note that the i–th column of $\mathbf{S}$ represents the strategy of player i, while the i–th row of $\mathbf{S}$ represents the evaluations *received* by player i. Accordingly we may denote by $\mathbf{p} := \sum_{j \in N} \mathbf{s}^j$ the vector of total valuations received by (and from) all players; and by $\mathbf{p}^{-i} := \sum_{j \neq i} \mathbf{s}^j$ the vector of total valuations received *from* all players but i. Observe that $\mathbf{p} = \mathbf{S} \cdot \mathbf{e}$, where $\mathbf{e} := (1, \ldots, 1)^\mathsf{T}$, so that $\mathbf{p}$ is a linear function, *viz* the sum, of the strategies $(\mathbf{s}^1, \ldots, \mathbf{s}^n)$.[4]

Come Dine with Me is, as well as any game of the class we are considering, a the-winner-takes-it-all contest where the prize v ($v \in \mathbb{R}_+ \setminus \{0\}$) is assigned to the player who receives the highest total evaluation; with a symmetric tie-breaking

[3] More generally we could allow for the set of possible evaluation values to be some closed subset of $\mathbb{R}_+$. Yet for the sake of tangibility, we prefer to present our results for a finite set of evaluation values, with 0 representing the lowest evaluation score; the generalisation to some arbitrary closed set is straightforward, though.

[4] More formally, $\mathbf{p}$ may be defined as the linear function $\mathbf{p} : \mathcal{M}(n, n, \mathbb{N}_{(k)}) \to \mathbb{N}^n_{(nk)} : \mathbf{S} \mapsto \mathbf{S} \cdot \mathbf{e}$, where $\mathcal{M}(n_1, n_2, \mathbb{N}_{(k)})$ denotes the set of $\mathbb{N}_{(k)}$-valued $n_1 \times n_2$–matrices.

rule, that is, in case of a tie the prize is split equally among the winners.[5] Let $\bar{p}(\mathbf{S}) := \max\{p_1(\mathbf{S}), \dots p_n(\mathbf{S})\}$ denote the maximum total evaluation received by some player for valuations $\mathbf{S}$; and let $W(\mathbf{S}) := \{j \mid p_j(\mathbf{S}) = \bar{p}(\mathbf{S})\}$ denote the winning players (players with maximal total evaluations) under $\mathbf{S}$. Using the symbol $\mathbb{1}$ to denote the indicator function, the payoff of player i is defined by the payoff function

$$u^i : \bigtimes_{i \in N} S^i \to \mathbb{R}_+ \quad : \quad \mathbf{S} \mapsto u^i(\mathbf{S}) = \mathbb{1}_{\{p_i(\mathbf{S}) = \bar{p}(\mathbf{S})\}} \frac{v}{|W(\mathbf{S})|},$$

and the payoff vector $\mathbf{u}(\mathbf{S}) \equiv (u^1, \dots u^n)(\mathbf{S})$ is defined accordingly.—With these elements at hand, we can now define the class of games we wish to work with.

Definition 1. A strategic form game Γ of the form $\Gamma = \langle N, (S^i)_{i \in N}, (u^i)_{i \in N} \rangle$ with

- a non-empty, finite set of players N,
- a collection of (n-dimensional) non-empty strategy sets S^i
- and a collection of payoff functions u^i (together with a positive prize z),

as defined above, is called a *mutual evaluation game (MEG)*.

Obviously, the game *Come Dine with Me* is a MEG with $n = 5$, $k = 10$ (that is, with $k + 1 = 11$ evaluation levels) and $v = 1000£$.

Observe that an evaluation game has a special feature: The payoff of each player depends only on the *total* scores of all players, *i. e.* on the vector $\mathbf{p} = \mathbf{S} \cdot \mathbf{e}$, but not single scores, collected in matrix $\mathbf{S}$. Accordingly, the payoff of player i can be written as a function of her own strategy $\mathbf{s}^i$ and of the *sum* of the strategies of the other players, $\mathbf{p}^{-i}$ or, more precisely, $\mathbf{p}^{-i}(\mathbf{S}^{-i})$:

$$u^i(\mathbf{S}) = u^i(\mathbf{s}^i, \mathbf{S}^{-i}) =: \tilde{u}^i(\mathbf{s}^i, \mathbf{p}^{-i}),$$

where, with the usual sloppiness, we write $\mathbf{S} = (\mathbf{s}^i, \mathbf{S}^{-i})$. Due to this feature, *Come Dine with Me* is an (n-dimensional) *aggregative game*—and thus the results obtained in the literature for this type of a game apply here.[6]

In the next section we characterise the Nash equilibria of a MEG, and illustrate our result by means of three examples.

[5]In *Come Dine with Me* the prize v equals 1000 £; in *Das perfekte Dinner*, 1600 EUR. However, we may consider any arbitrary but fixed amount $v > 0$.

[6]For the theory of aggregative games, though with scalar strategies, see Corchón (1994) and Jensen (2010).

5.3 Nash-Equilibria of Mutual Evaluation Games

Since total valuation received by player i, p^i, is linearly increasing in the evaluations awarded to her by the other players, $\mathbf{s}_i \equiv (s_i^1, \dots, s_i^n)$ (i-th row of $\mathbf{S}$), the payoff of player i is weakly increasing in $\mathbf{s}_i$. In contrast, the payoff of player j is weakly decreasing in p^i ($i \neq j$) and thus in s_i^j—irrespective of the strategies chosen by the other players $\mathbf{S}^{-j}$. Consequently, for each player it is a weakly dominant strategy to evaluate all players at the lowest level available, that is at level zero, implying that $\mathbf{S} = (\mathbf{0}, \dots, \mathbf{0})$ constitutes a Nash equilibrium in weakly dominant strategies, with resulting payoffs $\mathbf{u}(\mathbf{0}, \dots, \mathbf{0}) = (v, \dots, v)/n$. evaluate all other players with zero scores, and we therefore refer to this—Accordingly, we refer to this equilibrium as the *zero equilibrium.*—Since every MEG has a dominant strategy equilibrium, a Nash equilibrium consequently exists in any MEG. However, there are also other, non-zero Nash equilibria, as the following simple example shows.

Example 1. Let $N := \{1, 2, 3\}$ (*i. e.*, $n = 3$), and let $S^i := \{\mathbf{s} \,|\, \mathbf{s} = (s_1, s_2, s_3)^\top,\ s_j \in \mathbb{N}_{(1)}$ for $j \neq i,$ and $s_i = 0\}$. Thus, each player has $|S^i| = 4$ strategies, for example, the strategy set of player 1 equals

$$S^1 = \left\{ \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \\ 1 \end{pmatrix} \right\}.$$

This game has four equilibria:

$$\mathbf{S}_1^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \mathbf{S}_2^* = \begin{pmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \mathbf{S}_3^* = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix}, \quad \mathbf{S}_4^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix},$$

with total scores $\mathbf{p}(\mathbf{S}_1^*) = (0, 0, 0)^\top$, $\mathbf{p}(\mathbf{S}_2^*) = (2, 0, 0)^\top$, $\mathbf{p}(\mathbf{S}_3^*) = (0, 2, 0)^\top$ and $\mathbf{p}(\mathbf{S}_4^*) = (0, 0, 2)^\top$, and payoffs $\mathbf{u}(\mathbf{S}_1^*) = \frac{1}{3}(v, v, v)$, $\mathbf{u}(\mathbf{S}_2^*) = (v, 0, 0)$, $\mathbf{u}(\mathbf{S}_3^*) = (0, v, 0)$ and $\mathbf{u}(\mathbf{S}_4^*) = (0, 0, v)$.

The next example demonstrates that the number of equilibria rises quickly as we increase the number of evaluation levels, and thus the strategy set.

Example 2. This example extends Example 1 by allowing for three rather than two evaluation levels, *i. e.*, $S^i := \{\mathbf{s} \,|\, \mathbf{s} = (s_1, s_2, s_3)^\top,\ s_j \in \mathbb{N}_{(2)}$ for $j \neq i,$ and $s_i = 0\}$, where $\mathbb{N}_{(2)} := \{0, 1, 2\}$. Accordingly, each player has $|S^i| = |\mathbb{N}_{(2)}|^{(n-1)} = 3^2 = 9$

strategies. For example, the strategy set of player 1 equals

$$S^1 = \left\{ \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}, \begin{pmatrix} 0 \\ 0 \\ 2 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \\ 1 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \\ 2 \end{pmatrix}, \begin{pmatrix} 0 \\ 2 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 2 \\ 1 \end{pmatrix}, \begin{pmatrix} 0 \\ 2 \\ 2 \end{pmatrix} \right\}.$$

This game has 55 equilibria, which consist of 12 different types in the sense that permutations of the players "names" generate all of the 52 equilibria. These 12 types look as follows, assuming that player 3 is the winner of the contest.

$$\mathbf{S}_a^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \mathbf{S}_b^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix}, \quad \mathbf{S}_c^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 2 & 0 & 0 \end{pmatrix}, \quad \mathbf{S}_d^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 2 & 0 \end{pmatrix},$$
$$\mathbf{S}_e^* = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 2 & 1 & 0 \end{pmatrix}, \quad \mathbf{S}_h^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 2 & 2 & 0 \end{pmatrix}, \quad \mathbf{S}_j^* = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 2 & 2 & 0 \end{pmatrix}, \quad \mathbf{S}_l^* = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 2 & 2 & 0 \end{pmatrix},$$
$$\mathbf{S}_m^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 2 & 1 & 0 \end{pmatrix}, \quad \mathbf{S}_p^* = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 2 & 2 & 0 \end{pmatrix}, \quad \mathbf{S}_r^* = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 2 & 2 & 0 \end{pmatrix}, \quad \mathbf{S}_s^* = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 2 & 2 & 0 \end{pmatrix}.$$

These examples illustrate our results: Any mutual evaluation game possesses a Nash equilibrium in weakly dominant strategies where each player plays $\mathbf{s}^i = \mathbf{0}$; and we henceforth refer to this equilibrium as the *zero equilibrium*. Beyond this, any mutual evaluation game has many non-zero (weak) Nash equilibria, and their number grows rapidly in both the number of evaluation levels and the number of players. Moreover, for a non-zero tuple of strategies to constitute an equilibrium, the difference in total scores between any loser (non-winner) and some other player must be sufficiently large so as to guarantee that a loser cannot profitably deviate. For the same reason, in any non-zero equilibrium each winner evaluates all co-winners (split win)—if there are any—with a zero score. More formally we arrive at:

Proposition 1. Any mutual evaluation game possesses a unique Nash equilibrium in weakly dominant strategies where each player plays $\mathbf{s}^i = \mathbf{0}$ (the *zero equilibrium*), with resulting payoffs $u^i(\mathbf{S}) = v/n$, and multiple non-zero, weak Nash equilibria. Any equilibrium is characterised by two conditions:

1. Each winner assigns 0 to all other winners, *i. e.*, $s^i_j = 0, \forall i, j \in W(\mathbf{S})$.

2. For each loser i there is at least one other player j (who may be a loser or a winner) such that the difference between the total evaluations of j, $p_j(\mathbf{S})$—which in case j happens to be a winner equals $\bar{p}(\mathbf{S})$—and her own

total evaluation, $p_i(\mathbf{S})$, exceeds the evaluation which i awarded to j, that is, $\forall i \in N \setminus W(\mathbf{S}),\ \exists j \in N:\ p_j(\mathbf{S}) - p_i(\mathbf{S}) > s^i_j$.

The first property guarantees that a winner cannot increase her payoff by reducing the number of co-winners. Consequently, there must be a unique winner, unless the mutual evaluations of all winners equal zero. Observe, though, that this does not rule out that there are two or more winners in equilibrium. The second property ensures that even if loser i considers to reduce her evaluations of (some or all) other players to zero, there is at least one player who still has total higher evaluation than player i—so that it does not pay for player i to deviate from her chosen strategy. The following example illustrates this.

Example 3. Consider the game *Come Dine with Me*, that is a MEG with $n = 5$ players and 11 evaluation levels, *i. e.*, $s^i_j \in \mathbb{N}_{(10)}$. Assume that total evaluations amount to $\mathbf{p}(\mathbf{S}) = (20, 28, 12, 29, 5)^\mathsf{T}$—so player 4 is the unique winner. Consider player 1 with strategy $\mathbf{s}^1 = (0, 5, 3, 10, 1)^\mathsf{T}$. If player 1 reduces her award of player 4 to $\tilde{s}^1_4 = 0$, player 4 is no longer the winner of the game, and player 1 has a higher total evaluation than has player 4. Yet, player 1 still does not belong to the group of winners, for player 1 cannot avoid having a lower total evaluation than player 2 has (who is not a winner under $\mathbf{S}$ though). This is easily seen by subtracting the evaluations of player 1 from the total evaluations obtained by the players under $\mathbf{S}$: $\mathbf{p}(\mathbf{S}) - \mathbf{s}^1 = (20, 23, 9, 19, 4)^\mathsf{T}$. Accordingly, player 1 has no incentive to unilaterally deviate from her chosen strategy $\mathbf{s}^1$.—If a similar argument holds for the other players, $\mathbf{S}$ constitutes a (weak) Nash equilibrium.

5.4 Discussion of Observed Behaviour

In the previous section we have shown that the TV show *Come Dine with Me*, interpreted as a non-cooperative game in evaluation profiles,[7] belongs to a class of games which we labelled *mutual evaluation games (MEG)*. Furthermore, any MEG, and the game *Come Dine with Me* in particular, possesses one Nash equilibrium in weakly dominant strategies, the so-called *zero equilibrium*, where each player uses a vector of zero evaluations, and numberless weak Nash equilibria, where at least two players play non-zero strategy profiles. We now explore actual behaviour of participants in the German version of *Come Dine with Me* called *Das perfekte*

[7]More precisely, that part of *Come Dine with Me* where players evaluate each other's dinner party may be interpreted as a simultaneous non-cooperative game, *i. e.* a strategic game with almost perfect information, between the participants where their strategic variables are the evaluations. We focus on these evaluation strategies and abstract, in particular, from including the menu-selection decisions as part of the strategic game.

Dinner, and contrast our theoretical results with this observed behaviour. We then provide possible explanations for the prevailing off-equilibrium behaviour.

In the German format, no player (contestant) has ever played a zero evaluation vector in either of the 212 rounds played between 2006 and 2011, and accordingly the *zero equilibrium* has never been realised.[8] This is a remarkable observation as the *zero equilibrium* is a Nash equilibrium in weakly dominant strategies, *i. e.* the zero-evaluation vector constitutes a weakly best-reply for each player irrespective of the strategies chosen by the other players. In this sense, the choice of the zero-evaluation vector represents an apparently attractive strategy as it is (weakly) beneficial for any player, and it also yields the potentially largest payoff gain among all available evaluation strategies for any given strategy profile of the other players. For this reason, the *zero equilibrium* may veritably be regarded as highly appealing, standing out against any other Nash equilibrium, of which numberless exist.

Remarkably, the *zero equilibrium*, *i. e.* the equilibrium where all players choose $\mathbf{s}_i = \mathbf{0}$, has never been played in 212 rounds of *Das perfekte Dinner*. Furthermore, neither did non-zero equilibria emerge on a regular basis: In fact, only in one round has a non-zero equilibrium been played. This implies that in 211 rounds a contestant not receiving some prize money could have attained a larger prize by evaluating his contenders at lower scores. The presence of the potential for profitable deviation were so ubiquitous that even winners could increase their payoff in 33 rounds where the win was split among two (29 cases), three (3 cases) and four players (1 case). The possibilities for profitable deviation were not only omnipresent, but also so significant that even the very last ranked contestant could have attained an exclusive win in 43.88% and a shared win in 12.26% of the cases; and only in two cases deviating (by losers) had maximally brought about a split win only. In sum, equilibria are attained very rarely, and in this sense off-equilibrium behaviour is the rule rather than an exception in the German version of *Come Dine with Me*; and, in particular, the canonical candidate, the *zero equilibrium*, has never been played.

The most immediate explanation for this off-equilibrium behaviour is that with 11 evaluation levels (namely with levels $0, 1, ..., 10$) and five players the set of possible strategy profiles consists of $11^{20} \approx 672.75 \times 10^{18}$ different evaluation matrices, and accordingly the set of (weak) Nash equilibria is extraordinary large. Since during the show a contestant does not know the evaluations made (strategies chosen) by other contestants, and the number of non-zero equilibria is huge, there is virtually no chance for participants to coordinate on any of these (weak) equilibria. Consequently, a realisation of any of these non-zero equilibria may be attributed to

[8]The statistics we use are available in disaggregated form from the homepage of "Das perfekte Dinner" of the German TV-channel VOX broadcasting: http://www.vox.de/kochen/das-perfekte-dinner/details.

accident rather than to intention or coordination—and, in fact, an equilibrium was played only once.

Since the *zero equilibrium* is a Nash equilibrium in (weakly) dominant strategies, and may thus be regarded as highly appealing, we might expect participants to focus on this equilibrium. As this does not come about, there must be other factors which prevent participants from playing the *zero equilibrium*. The literature may provide several potential explanations for this behaviour, which we will now discuss: The impact of social pressure and reputation mechanisms, bandwagon effects, inequality aversion and sequential voting effects.

Concerning social pressure and reputation effects, a starting point is to realise that the *Come Dine with Me* show has some common features with joy-of-destruction games.[9] In these games, a player has the opportunity to reduce another player's wealth at some small cost without standing to gain anything except for the potential joy of destruction. One can consider the *Come Dine with Me* show as a variant of such a setting: Starting from a fair evaluation as the reference point, which regularly requires strictly positive evaluations, a contestant may choose to reduce his evaluation of the dinner of some or all other participants just for the joy of destruction (which may have its root in malevolence or enviousness). Clearly, a contestant may benefit from an under-evaluation of the performance of his co-contestants, but in those cases where a player does not obtain a higher payoff by decreasing another contestant's evaluation, *Come Dine with Me* features similarity with a joy-of-destruction game.

Moreover, a strategy of under-evaluation, and in particular the zero strategy, can be played in anonymity during the show, so that a destructive strategy remains undisclosed *in mediis*. Abbink and Sadrieh (2009) and Abbink and Herrmann (2011) conduct joy-of-destruction experiments, where there is a chance that burning money remains hidden. They find that money burning rates increase significantly when there is a degree of anonymity involved. However, in the *Come Dine with Me* show disaggregated voting behaviour will be made public to both the other contestants and millions of viewers about three months after the contest when the show is eventually broadcast. Thus, there is a delayed publicity effect. In his seminal article Bernheim (1994, p. 844) concludes: "When popularity is sufficiently important relative to intrinsic utility (defined as utility directly derived from consumption), many individuals conform to a single, homogeneous standard of behaviour, despite heterogeneous underlying preferences". Therefore, one potential explanation for the off-equilibrium behaviour in the actual show is that publicity keeps people from playing the zero strategy. In this vein, Holländer (1990) and Benabou and Tirole

[9] For a general description of joy of destruction games and some experimental results see for example, Zizzo and Oswald (2001); Zizzo (2003).

(2006) provide further evidence that such an effect might play an important role.

Beyond publicity effects, people may condition their present behaviour on previously observed behaviour—and in this sense, bandwagon effects may arise. Aardema et al. (1977) show that contestants condition their evaluations on evaluations given in previous shows. Consequently, if contestants observe relatively high evaluations in shows already broadcast, this may affect their present voting behaviour as they do not want to endanger their reputation by deviating from an established social norm. Similarly, Young (1996) finds that stable focal points, such as, for example, a 50:50 division in a bargaining game, often evolve over time until they become focal eventually. In this way, a social standard may be established in initial shows requiring contestants to refrain from playing the zero strategy. If this implicit rule is accepted—again implicitly—by subsequent contestants, this might explain why we never observe the *zero equilibrium*.

Furthermore, inequality aversion of contestants might be relevant. Fehr and Schmidt (1999) introduce a utility function based on inequality aversion to explain the behaviour in different experiments. They argue that people are averse of outcomes that are distant from a previously established social standard, in particular with respect to negative deviations. For the setting of *Come Dine with Me* this implies that contestants are more willing to give evaluations which are too positive rather than too negative, relative to a social standard calling for fair evaluations. The average evaluation in the German version of the show between 2006-2011 is 7.57 points, and we rarely observe any evaluations below 4. Moreover, a positive bias attributable to inequality aversion may provide a possible explanation for this generous evaluation behaviour. Both reasons may contribute to explaining why contestants rarely play strategies with low evaluations which might actually improve their chances of winning considerably.

Finally, the sequential effect already recognized by Haigner et al. (2010) for *Das perfekte Dinner* and by Page and Page (2010) for the Idol series[10] may provide another explanation for off-equilibrium behaviour. Both articles find that contestants performing later in the respective show receive higher evaluations. One explanation for this effect is that later contestants adapt to previous performances via so-called direction-of-comparison effects: "It appears that judges form an impression of each new option by comparing it to those that preceded it. Using that option's features as a 'checklist,' more weight is given to unique ones than to ones shared with previous options. This unidirectional comparison process produces increasing ratings in options with unique positive features, and decreasing ratings when options have unique negative features." (see Bruine de Bruin and Keren, 2003, p. 91). Contes-

[10]The Idol series is broadcast in UK under the title "Pop Idol", in the US as "American Idol" and in Germany as "Deutschland sucht den Superstar".

tants cannot change their menu in the *Come Dine with Me* show once the contest has started, and the skill of a chef is unlikely to change significantly over the course of the contest week. Hence, the only way for a contestant to adapt his behaviour in response to the performance of his precursors is to invest more money and effort to enhance decoration, to engage an artist for a performance during the dinner etc. If these improvements are performed, contestants may induce an upward shift in the perceived socially acceptable evaluation—and sequential effects of this type can help to explain why we do not observe low evaluations.

5.5 Conclusion

In this paper we looked at the TV-Show *Come Dine with Me* from a strategic perspective. To this end, we interpreted and modelled this show as a simultaneous non-cooperative game with purely self-regarding preferences of the players (*viz.* contestants) and mutual evaluation levels as their strategic variables. We showed that *Come Dine with Me* belongs to a class of games to which we refer as *mutual evaluation games (MEG)*. Each MEG possesses multiple Nash equilibria, each of which is characterised by two conditions: (1) Each winner assigns a zero score (lowest possible score) to all other co-winners, if there are any; (2) For each loser there is at least one other player (who may be a loser or a winner) such that even if this loser were to evaluate all other players with a zero score, there is still (at least) one contestant who has a higher total score. Thus, in equilibrium, any winner cannot reduce the number of co-winners (condition 1); while any loser may affect the set of winners, but cannot accomplish to become a member of the group of winners (condition 2).

We showed that in a game with three contestants (players) and two evaluation levels has four Nash equilibria. Adding one additional evaluation level, we find that the resulting three-player game with three evaluation levels possesses 55 equilibria—and this number quickly soars as the number of players or evaluation levels increases. Also, irrespective of the number of players and the number of evaluation levels, any MEG possesses a unique Nash equilibrium in weakly dominant strategies: the *zero equilibrium* in which all players evaluate each other with zero scores. As long as we disregard (potential) social preferences and fairness considerations and, thus, focus on the monetary gains exclusively, this *zero equilibrium* may arguably be regarded as *the* appealing equilibrium, standing out against any other equilibrium.

We contrasted our theoretical results with actual behaviour in the German version of the show. The *zero equilibrium* has never been played in any show during 2006-2011. In fact, only in four cases did a contestant evaluate another contestant with a zero score. Furthermore, players typically failed to reach any equilibrium: only in one out of 212 rounds an equilibrium is attained. In this sense, off-equilibrium behaviour is the standard result observed in actual behaviour. Considering that the number of equilibria in a 5 player/11 evaluations space is remarkably large, one explanation for this observed off-equilibrium behaviour is that contestants simply cannot coordinate on any equilibrium. However, contrasting the average evaluation of 7.57 with the arguably appealing *zero equilibrium*, it becomes clear that there must be other factors than payoff concerns, that bring about this differential.

We provided four different potential explanations for this phenomenon: The impact of social pressure and reputation mechanisms, bandwagon effects, inequality aversion and sequential voting effects. We showed that all effects can help to explain off-equilibrium behaviour and the seemingly positive evaluation bias. All of these explanations, if the proved to be correct, suggest that the alleged identity of monetary payoff and utility does not apply here, and that the players' objective functions must be adapted accordingly. With suitably modified objective functions we obtain a new game, an equilibrium of which may then provide more accurate predictions for real bahaviour. Yet, as long as the game has several equilibria the equilibrium-selection problem still applies.

In sum, the goal of this paper was to provide a game theoretical background for this type of mutual evaluation games, and to provide potential explanations for actual behaviour compared to the game-theoretical predictions. Future research on this topic should focus on empirically measuring the impact of factors that may help to explain actual behaviour in a mutual evaluation game such as *Come Dine with Me*.

Chapter 6

Pro-Social behavior in the TV format *Come Dine with Me*: An empirical investigation.

6.1 Introduction

Interaction between human beings is, to a large extent, governed by social norms that have evolved over time and have been instilled in us since childhood. In the absence of compliance to social norms, everyday interaction would be difficult because every situation would require the persons involved to establish acceptable behavior anew or to coordinate regarding some mutually acceptable behavior. Compliance with a social norm can be enforced through so-called moralistic punishment. Moralistic punishment is defined as: "... the enforcement of social norms by outraged but otherwise not directly affected third parties" (Carpenter and Matthews (2012), p. 555). Another important dimension that leads people to adhere to norms is the potential loss of reputation in the eyes of their peers, often termed social approval (Benabou and Tirole, 2003, 2006; Bernheim, 1994; Holländer, 1990). In his seminal article, Bernheim (1994) postulates: "When popularity is sufficiently important relative to intrinsic utility (defined as utility directly derived from consumption), many individuals conform to a single, homogenous standard of behavior, despite heterogeneous underlying preferences" (p. 844). Bernheim's model also allows for deviations from a norm for agents with extreme preferences. This explains the need for third party punishment, because in certain situations the intrinsic utility gain may lead to deviations from the norm.

The aim of this paper is to analyze the influence of social approval, reputation, and personal traits on the voting behavior of contestants in the German version of the TV show "Come Dine With Me." In order to address these questions, we employ a dataset including shows from the years 2006-2011. The German version is called "Das perfekte Dinner," and for clarity of exposition, we will refer to the German version of the show as "The Perfect Dinner" in the rest of this paper. The TV show offers a unique setting to test the impact of these factors because contestants' ratings are concealed, and therefore, are unobservable by the co-contestants during the show and are not revealed to the public and contestants until the final broadcast. Thus, due to the fact that voting behavior is unobservable during the show, one might expect contestants to behave selfishly in order to win a monetary prize, if it is assumed that they do not care about any social effects. Yet there are various other factors that may interact with voting behavior having a social component, such as the order in which the contestants cook, whether or not a person has already cooked, and the social similarity of the contestants. In order to assess the influence of these factors, we estimate several different regression models that explain the evaluation scores a cook receives from an evaluator.

Our work adds to the literature addressing the impact of social factors on economic decisions in several ways. First, we have a richer dataset than previous studies on the TV show "The Perfect Dinner," and thus, are able to explore effects stemming from social and reputational effects in a more robust fashion. Furthermore, we go beyond preceding studies by investigating new issues such as: the effect of objective sophistication, social similarity between persons, the effect of past voting behavior, and the effect of a prior performance. Second, we supply empirical evidence for theoretical models related to the impact of social factors on economic decision making. By addressing a range of potential social factors which has not been examined previously in this context, this paper can serve as input in a range of theoretical specifications. We find that reputational factors do not play a role. In contrast, the social similarity between persons, whether a person already has cooked, and the order in which contestants cook all play a significant role in explaining voting behavior. Furthermore, objective sophistication also has a significant impact and renders our results more robust than previous approaches. The rest of the paper is structured as follows: Section 2 describes in detail the rules and the course of action in the TV show "The Perfect Dinner" and offers an overview of the economic literature related to behavior in TV shows. In section 3, we describe our data and formulate our hypotheses regarding contestants' behavior. In section 4, we explain our econometric approach, which is followed by a discussion of our results in section 5. Finally, we conclude in section 6.

6.2 Description of "The Perfect Dinner" and literature review

The original format of the show was first broadcast in Great Britain in 2005 under the title *"Come Dine With Me."* Since then, identical or very similar formats have been picked up for broadcasting in 32 countries worldwide[1], and reach a large audience[2] in their respective countries. The German version of the show, *"The Perfect Dinner,"* has the following rules: Each day, one of the five contestants cooks for the whole group. Thus, the overall time span of one round is five days. The dinner is prepared at the respective home of the cook. Contestants must announce the menu they plan to cook before the beginning of the show and cannot change it afterwards. Furthermore, they do not have any influence on the order of cooking, which is determined by the TV-Chanel producing the show. Each contestant receives 600€ for expenses before the show. At the end of the respective dinner, the performance of a cook is rated by his peers on a scale from 0-10, with 10 representing the highest

[1] For example, the German format is called Das perfekte Dinner (since March 2006); the French, Un Diner Presque Parfait (since February 2008); the Turkish, Yemekteyiz (since October 2008), etc.

[2] See, for example, `http://en.wikipedia.org/wiki/Come_Dine_with_Me`.

score. This score does not only reflect the quality of the food, but also the overall impression of the evening, meaning that the ability of the host to make it an overall enjoyable experience for the contestants is rated as well. Evaluations are performed confidentially, so that each contestant has to decide on his evaluation with no knowledge of the evaluations of his competitors. Furthermore, communication regarding this matter is prevented by the TV crew. Evaluations remain undisclosed until the show is broadcast, approximately three months later. At the end of the week, the results, although not detailed individual evaluations, are announced and the contestant with the highest total collective score wins a prize of 1500€. If there is a draw, the prize is divided equally among the winners.

Despite the great popularity of the show, there are only a few studies that investigate "The Perfect Dinner" from an economic standpoint. Haigner et al. (2010) consider the sequential position effects of the German version and find that a negative position effect exists for the first competitor. Ahmed (2011) compares the means of points given in the Swedish version of the show and finds no significant differences between the voting behavior of men and women. citeSchuller2013 consider the show from a game theoretical point of view. They model it as a simultaneous non-cooperative game with evaluations as strategic variables and show that, in the absence of social concerns, there are many Nash-equilibria. Employing part of the same data set used for this study, they find that players reach a Nash equilibrium only once and that this equilibrium differs from the zero-equilibrium. Therefore, non-equilibrium behavior seems to be the rule rather than the exception.

The literature concerning economic behavior on TV shows has seen a significant increase, especially in recent years. Bennett and Hickman (1993) study the show "The Price is Right" with respect to the rationality of decision making and learning, and find that learning occurs during the show that renders contestants' behavior more effective from an economic point of view. Berk et al. (1996) study the same show also with respect to the rationality of agents in the context of the bounded rationality theory. They also find that the initial behavior of contestants is sub-optimal from an economic perspective, but improves over time as contestants learn. However, they also show that frequently, rule-of-thumb strategies are employed because rational expectations strategies seem to be too complex. Anwar (2012) examines the TV show "Street Smarts," testing for discrimination, and finds that non-blacks discriminate against blacks in evaluating their ability to answer certain types of questions. Because this discrimination does not occur in the general knowledge category, he concludes that it does not lend support to the statistical discrimination hypothesis. van den Assem et al. (2011) look at cooperative behavior in the show "Golden Balls" with respect to learning and social interaction. They find that learning that concerns expected earnings does occur and that people tend to show reciprocal preferences. Both factors influence cooperative behavior over time. Furthermore, the sizes of the potential prizes matter, as higher potential earnings lead to less cooperation. Page and Page (2010) consider the sequential bias within the setting of the "Idol" show and find that the data reveal a bias.

6.3 Data Description and Hypotheses

6.3.1 Data description

All data were obtained from the TV channel VOX, which broadcasts "The Perfect Dinner," by collecting data from their website and re-watching episodes to obtain missing data[3]. The ratings for the show during the time period investigated (2006-2011) were kindly provided by VOX. We excluded the first 24 weeks of our dataset for estimating all but one specification of the econometric models, where we test for the effect of the initial 24 weeks on voting behavior. They are excluded as they represent the time span between the filming and the broadcast of the first show. Since one of the factors we want to measure is the impact of past evaluation behavior, we must exclude this time span in all but one specification because there is no possibility for contestants to have any knowledge about previous voting behavior prior to the first broadcast. Without the first 24 weeks, the final sample consists of 3735 cooking assessments observed in 237 rounds of games. Including the first 24 weeks leads to 4322 observations.

Table 6.1 gives an overview of the descriptive statistics for the variables used in the econometric analysis, discussed in more detail in section 4. The points given to the cook by the other contestants are set as a dependent variable ("Points"). Its distribution is skewed to left which is due to the very rare occurrence of poor evaluations. The mode and median both take the value of eight and hence are relatively close to the highest possible value. Table 6.2 displays the distribution of "Points" for the estimation sample. The weekday (Monday-Friday) the contestant to be evaluated is performing enters the econometric model as a set of four binary indicators each indicating one weekday (Tuesday-Friday). Monday is the base category and therefore does not appear in the table. Since the time schedule does not vary across rounds, the weekday and the order of cooking are equivalent. That is cooking on Monday implies cooking first, cooking on Tuesday implies second, etc. "Evaluator Already Cooked" is equal to one if a participant has already cooked at the time he must evaluate a dinner and equals zero otherwise. "number of ingredients" represents the absolute number of ingredients used in a diner. "number of

[3]Part of our data set is available in a disaggregated form on the German TV channel VOX broadcasting homepage of "Das perfekte Dinner":`http://www.vox.de/kochen/das-perfekte-dinner/details`.

ingredients^2/100" is the square of "number of ingredients", divided by 100. This factor of division is used to ensure that the explanatory variables are numerically of similar magnitude, rendering the estimation procedure more stable and the coefficients more easily comparable. "Level" measures the difficulty level, "price" the price level of menu[4] . "Av. evaluation level," reports the average points given during the last 24 weeks before a contest. "Av. share viewers" represents the tv-market share of the respective show. The minimum equals 7.85%, while the maximum is 12.23%. For example, if 10 million people were watching TV on Monday during the airing of "The Perfect Dinner", a 10% share implies that 1 Million people were watching the show. A five percentage point difference might not seem large, but for a show in the relevant market segment, this represents the difference between a mediocre and a successful show. "Population" measures the size of the population in the town in which the show is being filmed in millions of inhabitants. For example, the largest city in our sample with 8,1 million inhabitants has a value of 8,1, the smallest with 8000 inhabitants a value of 0,008. "Foreign" accounts for the filming of the show in locations outside of Germany, the value being 1 if it is outside and 0 if the show takes place in Germany. "Time" is the number of days since the first recording of the show divided by 1000. "time^2/1000" is the square of "time" divided by 1000 [5]. The division factor of 1000 has been chosen in order to ensure better comparability between the coefficients in our analysis later on. Furthermore, we report the descriptive statistics on a range of individual characteristics such as gender, migration status, age, profession and hair color. Besides age, all individual characteristics are dummy variables. "dissimilar" measures the social dissimilarity of the evaluator and the cook, based on the range of individual social characteristics, listed in table 6.1. The closer the value is to one, the less similar the two contestants are. In computational terms, "dissimilar" is the rescaled Mahalanobis distance between the vectors of two participants' socioeconomic characteristics[6].

As a scaled Mahalanobis distance the variable dissimilarity is constructed from weighted sum of squared (and cross-products of) deviations in the considered socioeconomic characteristics. Hence it is meant to capture a potential effect of overall socioeconomic proximity between cook and evaluator. One may, however, question a

[4]The difficulty level and the price level are determined by experts on the website `http://www.kochbar.de.`

[5]The division factor of 1000 is chosen in order to ensure similar magnitudes of the explanatory variables; see above.

[6]The Mahalanobis distance (MDij) is defined $\sqrt{(x_i - x_j)' \, \mathrm{V}(x)^{-1} (x_i - x_j)}$ with xi and xj denoting the column vectors of socioeconomic characteristics of individuals i and j, respectively, and V(x) denoting the (estimated) variance-covariance matrix of socioeconomic characteristics x. The variable dissimilar is defined $\mathrm{MD}_{ij}/\max(\mathrm{MD})$. That is, dissimilar is normalized to one for the most differential pair of individuals in the sample, while it takes the value of zero for a pair of individuals who share all considered socioeconomic characteristicshe Mahalanobis

general effect of dissimilarity and argue that it is rather dissimilarity with respect to specific characteristics that matters. Moreover, similarity in these relevant characteristics may not have a homogeneous effect on the depended variable. Dissimilarity with respect to age for example, might result in less complaisant evaluations while heterogeneousness with respect to gender might result in more positive evaluations. In order to address this argument, we also estimated specifications that separately include squared deviations in specific socioeconomic characteristics as explanatory variables. As most characteristics enter the model as indicators, these variables - with the exception of age – are dummies indicating a difference with respect the considered characteristic. Because of (near) collinearity, the data does not allow for estimating a model with full set squared deviations and we focus on a subset of characteristics (gender, immigration status, age, hair color), see Table 6.1.

Table 6.1: Descriptive Statistics

	Mean	**S.D.**	**Median**	**Min**	**Max**
Points	7.616	1.363	8	1	10
cooking order					
Second	0.203	0.402	0	0	1
Third	0.202	0.401	0	0	1
Fourth	0.200	0.400	0	0	1
fifth	0.193	0.395	0	0	1
evaluator already cooked	0.500	0.500	0	0	1
number of ingredients	52.633	16.945	51	16	134
number of ingredients2/100	30.573	21.594	26.01	2.56	179.56
level	1.874.675	.3459764	2	1	3
price	1.859.798	.3616571	2	1	3
av. evaluation level (previous 24 weeks)	7.597	0.272	7.552	7.073	8.123
av. share viewers (previous 24 weeks)	9.470	1.564	8.332	7.846	12.234
population (city of venue)	0.989	1.099	0.580	0.008	8.100
foreign (city of venue)	0.035	0.185	0	0	1
time	1.110	0.491	1.206	0.273	1.908
time2/1000	1.474	1.094	1.454	0.075	3.640
ind. characteristics					

female	0.534	0.499	1	0	1
immigrant	0.074	0.263	0	0	1
age	38.284	11.177	38	18	71
student	0.070	0.255	0	0	1
civil servant	0.032	0.175	0	0	1
artist	0.071	0.256	0	0	1
entrepreneur	0.210	0.408	0	0	1
pensioner	0.006	0.077	0	0	1
employee	0.533	0.499	1	0	1
academic	0.089	0.285	0	0	1
trainee	0.009	0.096	0	0	1
pupil	0.009	0.092	0	0	1
blond	0.377	0.485	0	0	1
dissimilarity					
overall dissimilarity (Mahalanobis dist.)	0.344	0.162	0.337	0	1
female (squared diff.)	0.593	0.491	1	0	1
immigrant (squared diff.)	0.133	0.340	0	0	1
age (squared diff.)	0.262	0.341	0.121	0	2.500
blond (squared diff.)	0.471	0.499	0	0	1

Table 6.2: Distribution of dependent variable (Points)

value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
abs. frequency	1	2	17	53	152	450	1031	1073	643	313
cum. percentage	0.03	0.08	0.54	1.95	6.02	18.07	45.68	74.4	91.62	100

6.3.2 Research Hypotheses

Our hypotheses address several issues which we group into the following categories: Monetary incentives, reputation, social in-game influences, objective quality, and personal traits. The main monetary incentive is the cash prize. However, because the prize has not changed over the years, the monetary motivation (e.g., change of the prize) can be disregarded, and thus, extrinsic motivation does not vary across observations and for this reason cannot be analyzed on basis of our data. To approximate the impact of reputation on our dependent variable, we consider the impact of past voting behavior. This hypothesis is derived the work of Bernheim (1994) and Benabou and Tirole (2006). Bernheim (1994) considers the emergence of customs or why people tend to conform to certain social standards. His model explains conformity by comparing the relative value of popularity to intrinsic utility, and shows that agents with non-extreme preferences choose to conform to a norm in equilibrium. Benabou and Tirole (2006) consider a model in which people also care about appearing pro-social, depending on the visibility of their actions. Since voting behavior is visible to the public once the show is aired, past voting behavior can be considered as a social norm current contestants want to conform to. In the literature this behavior is often associated with the term "bandwagon" effect (Aardema et al., 1977). If a high level of evaluations has evolved as a "social" focal point (Schelling, 1960) over time, this might help to explain the voting behavior of participants. (Young, 1996) shows that focal points such as a 50:50 split in bargaining situations are not focal right away, but evolve over time and remain stable afterwards. We control for the influence of past voting behavior by including the independent variable "Average evaluation level," which reflects the average points given over the last 24 weeks. Our first hypothesis is then as follows:

H1: "The higher evaluations have been in the past, the higher evaluations are today."

Concerning social in-game influences, we first consider potential direction-of-comparison effects caused by the sequential voting structure of the show. Direction-of-comparison effects can influence voting behavior in the following way:

"It appears that judges form an impression of each new option by comparing it to those that preceded it. Using that option's features as a 'checklist,' more weight is given to unique ones than to ones shared with previous options. This unidirectional comparison process produces increasing ratings in options with unique positive features, and decreasing ratings when options have unique negative features." (Bruine de Bruin and Keren (2003), p. 91).

We use the starting position of a cook to measure this. Haigner et al. (2010) find that in "The Perfect Dinner," first day contestants are evaluated significantly more harshly than contestants who cook later. However, the authors do not control for a range of effects that we consider: the effect of objective quality, the effect of being socially similar to another person, the effect of past voting behavior and the effect of having already performed. We expect to see an overall positive evaluation bias for contestants that perform later, since subsequent cooks can adjust the performance elements of their dinner (e.g., having an artist perform, playing music themselves, etc.) and gather more information about other contestants (e.g., sympathy or preferences). Of course, unique negative performances of later cooks will lead to a lower rating, but overall contestants that cook at a later stage in the game have a better chance to adjust to the expectation of the group. Due to this process we expect to see an overall positive effect of cooking later. Our second hypothesis is then the following:

H2: "The later a contestant performs, the higher the evaluations he receives."

The variable "Already Cooked" indicates whether the evaluator has competed before the contestant to be evaluated. This controls for the effect that once a participant has cooked, he might be more critical of another's performance since he will not be evaluated again. Put differently, we are controlling for contestants overestimating their own performance. This is a recognized phenomenon in the psychological and economic literature[7]. Moore and Healy (2008) find that overestimation especially plays a role when difficult tasks are performed. Arguably, preparing a three course dinner for 5 persons can be categorized as such a task, and might lead a contestant to overestimate his own performance. Our third hypothesis is then the following:

H3: "The earlier a contestant performs, the lower the evaluations the contestant gives to the remaining cooks."

In order to test for the influence of objective measures, we use the total number of ingredients used in the three dishes prepared on one day, the price and difficulty level. Our fourth hypothesis concerning the effect of the objective characteristics of a dinner is then the following.

H4: "The more sophisticated a performance is, the better the evaluations."

Concerning personal traits, we separate our analysis into two parts: In the first part we consider an aggregate measure of dissimilarity between contestants, measured by the variable "Overall Dissimilarity". We expect participants who have dissimilar social characteristics to give each other lower evaluations. This effect has been recognized in the experimental economic and psychological literature (Brañas Garza et al., 2010, 2012; Engel, 2011). Our fifth hypothesis is then the following:

[7]For a good overview on both literature fields, we point the reader to Moore and Healy (2008).

H5: **"The less similar two contestants are, the lower their mutual evaluations."**

As a second step, we take a closer look at what specific characteristics exert the strongest influence on the aggregate dissimilarity measure. We will not specify a range of hypotheses for each characteristic. Instead, we will present a table with specific results for some traits and their impact on the aggregate measure and discuss the individual impact each factor has[8]. The next section presents our econometric approach in order to answer these questions.

6.4 Econometric Approach

In order to analyze which factors determine the observed evaluation scores, we set up a variety of regression models. We start with a simple model specification using ordinary least squares to estimate the effects the explanatory variables exert on the evaluation scores ("Points"). As a result of the design of the show, the observations – that is, the assigned scores – are not statistically independent, as one dinner is evaluated four times and each contestant issues four evaluations. Hence, unobserved heterogeneity, both at the level of dinners (and respectively, cooks) and at the level of evaluators, generates a complex pattern of error correlation within each round of the show. One approach to address this issue is to parametrically model this correlation and to estimate the model using generalized least squares. Although this approach is efficient given the validity of the distributional assumptions, we follow a more simple and robust modeling strategy by calculating clustered standard errors where clustering is at the levels of rounds of the game. Since clustering allows for arbitrary error correlation within each cluster (Moulton, 1986), clustered standard errors implicitly account for either source of error correlation. One may, however, argue that unobserved heterogeneity is not only an issue of error correlation, i.e., efficiency and correctly estimated standard error, but also matters for the consistency of the estimation procedure. This applies if the unobserved characteristics of dinners and evaluators are correlated with the explanatory variables. Given the structure of the data at hand, one could account for this by estimating a two-way-fixed effects model (Wansbeek and Kaptyen, 1989) that includes indicators for each dinner and each evaluator. In addition to being inefficient if individual effects are uncorrelated with the regressors, the obvious drawback of this approach is that it allows for the identification of only very few coefficients of interest, that is, those that are neither constant for dinners/cooks nor for evaluators. In the reference specification the only two are the coefficients attached to "already cooked" and "dissimilar." Yet the ef-

[8] We thank an anonymous referee for pointing us into this direction.

fects of those variables that do not vary for both dinners and evaluators are already absorbed in the fixed effects. Interestingly, estimates for the former two coefficients are similar for ordinary least squares (OLS) and two-way fixed effects. Moreover, the conventional Hausman test does not favor one-way fixed effects over conventional random effects that explicitly account for the unobserved characteristics of evaluators. Both results indicate that a correlation of unobserved characteristics and explanatory variables are unlikely to represent a major problem. This makes perfect sense, as several regressors, such as "cooking order," "dissimilar," and "share viewers" are virtually randomly assigned to cooks and evaluators, and hence, by construction, are uncorrelated with unobserved heterogeneity. Therefore, we adhere to OLS and clustered standard errors[9].

One obvious objection to employing OLS is the ordered nature of the dependent variable, which calls for a parametric ordered regression model such as ordered probit or ordered logit. As a robustness check, we ran ordered probit regressions that yielded coefficient estimates very similar to OLS. In addition to this reassuring result, the argument in favor of employing an ordered model may not be as clear-cut as it seems at first glance. Although the scores are ordinal, evaluators may view them as cardinal measures.

Testing for a time effect on the assigned scores is of crucial relevance to the present analysis. Several different specifications are tried, e.g., time dummies, a linear trend and both a linear and a quadratic trend, with the latter specification serving as the preferred specification. Yet not only do changes in the level of assigned scores matter, but also changes in their variance. To address this issue, we also estimate a linear regression with multiplicative heteroscedasticity (Harvey, 1976) in which the error variance is specified either as a linear or as a quadratic function of time.

The basic model specification includes average evaluations and the average share of viewers for the previous 24 weeks. This does not allow for considering the initial 24 weeks in the regression analysis since these two variables are undefined for this subset of observations. As a robustness check we try an alternative specification that considers all available observations (Model 3). It includes a dummy indicating the initial period and let the average evaluations and the average share of viewers enter the model as interactions with one minus this indicator. In this specification the effect of average evaluations and the average share of viewers is, hence, 'switched off' for the initial period.

One important question in the analysis is whether the true quality of a dinner is

[9]To take account of the error term's most likely departure from normality, we also tried clustered bootstrapped standard errors for all model specifications. Yet it turned out that they just marginally deviate from the reported analytic ones.

an important determinant of the scores assigned by the evaluators. Analyzing the effect of quality is obviously hampered by the fact that "true quality" is not observed and may not even exist, as quality is a matter of preference. What is – at least to some extent - observed in the data is a dinner's level of sophistication, primarily the number of ingredients, which may be regarded as an approximation for quality. In an alternative variant of the model (Model 4) we examine the role of objective characteristics in more detail by also including the level of difficulty (assessed by external experts) and the monetary costs of preparing the dinner. Moreover we take account of the argument that the link between quality and sophistication may not be monotone by including the squared number of ingredients as another regressor. That is, we allow for an overreaching level of sophistication doing more harm than good to a dinner's quality.

In order to identify with respect to which individual characteristics dissimilarity between cook and evaluator matters start with the basic model specification that includes a single overall measure of dissimilarity, see section 3. Then we exclude specific characteristics from this overall measure and let them enter the model individually as squared cook-evaluator differences (Model 5). We check how the level of significance (p-value) of the (residual) overall dissimilarity changes. A substantial increase of the p-value indicates that the excluded characteristic is of major importance for the effect of overall dissimilarity. A substantial decrease of the p-value, however, may indicate that dissimilarity with respect to the excluded characteristic acts in the opposite direction than the estimated coefficient of the overall measure suggest. We also report the estimated coefficient of the squared cook-evaluator deviation of the respective characteristic, in order to cross-check these results.

The regression equation for the reference model can be written:

$$\begin{aligned}
&Points_{ijr} = \beta_0 + \beta_{pos2} * Cooking_second_{ir} + \beta_{pos3} * Cooking_third_{ir} \\
&+ \beta_{pos4} * Cooking_fourth_{ir} + \beta_{pos5} * Cooking_fifth_{ir} + \beta_{cooked} * Already_Cooked_{ijr} \\
&+ \beta_{pts24} * Average_Evaluation_Level_r + \beta_{spec24} * Share_Viewers_r + \beta_{pop} * Population_r \\
&+ \beta_{ing} * Ingredients_{ir} + \beta_{foraign} * Foreign_r + \beta_{time} * Year_r + \beta_{timesq} * Year_SQ_r \\
&+ \gamma'_{cook} x_{ir} + \gamma'_{evaluator} x_{jr} + \beta_{similar} * dissimilar_{ijr} + \epsilon_{ijr}
\end{aligned} \tag{6.4.1}$$

The unknown coefficients β and γ are subject to estimation and ε denotes a random error term. Note that i indexes cooks and j indexes evaluators, while r indexes rounds of the show. Hence, the above equation indicates that some regressors only vary between the rounds of the show (indexed with r) and some other regressors vary within rounds across cook (indexed ir) or across evaluators (indexed jr), while very few vary across both cook and evaluators (indexed ijr). For the robustness check concerning the initial 24 weeks the regression equation is modified as follows:

$$
\begin{aligned}
&Points_{ijr} = \beta_0 + \beta_{pos2} * Cooking\_second_{ir} + \beta_{pos3} * Cooking\_third_{ir} \\
&+ \beta_{pos4} * Cooking\_fourth_{ir} + \beta_{pos5} * Cooking\_fifth_{ir} + \beta_{cooked} * Already\_Cooked_{ijr} \\
&+ \beta_{pts24} * (1 - Initial24_r)Average\_Evaluation\_Level_r + \beta_{spec24}(1 - Initial24_r) * Share\_Viewers_r \\
&+ \beta_{pop} * Population_r + \beta_{ing} * Ingredients_{ir} + \beta_{foraign} * Foreign_r + \beta_{time} * Year_r \\
&+ \beta_{timesq} * Year\_SQ_r + \gamma'_{cook} x_{ir} + \gamma'_{evaluator} x_{jr} + \beta_{similar} * dissimilar_{ijr} + \epsilon_{ijr}
\end{aligned}
\tag{6.4.2}
$$

with $Initial24_r$ indicating the initial 24 weeks. In the specification that focuses on the objective characteristics of a dinner, equation (6.4.1) is augmented by $\beta_{ingsq} * Ingredients^2_{ir} + \beta_{level} * Level_{ir} + \beta_{price} * Price_{ir}$. Finally, the specification that focusses on the role cook-evaluator dissimilarity replaces $\beta_{similar} * dissimilar_{ijr}$ in (1) by $\beta_{similar} * dissimilar^{res}_{ijr} + \theta(z_{ir} - z_{ir})^2$ with z representing a subset of x and dissimilarres denoting the Mahalanobis distance of the vectors of those individual characteristics that are not included in z.

6.5 Empirical Analysis and Discussion

6.5.1 Results

In table 6.3, we report the results for the following estimations: "OLS reference", "ordered probit (Model 2)", "OLS including the initial 24 weeks" (Model 3), "OLS with ingredients^2 (Model 4)" and "OLS with deviations in cook evaluator characteristics (Model 5)". Estimates of the coefficients for individual characteristics (age, gender, occupation) are reported in table 6.4 and will also be discussed. In table 6.5 we report the effect of excluding "female", "migrant", "age", and "blonde" from the aggregate "dissimilarity measure".

Our first hypothesis sought to answer the question of whether voting behavior in the past sets a sort of standard which influences voting behavior in later shows. We measured this by including the variable "Av. evaluation level," which is the average evaluation level over the last 24 weeks. The variable does not have a significant influence in any of the models. One possible explanation for this is that current contestants do not watch past episodes on a regular basis. Furthermore, the objective quality and a range of other social factors we consider in our analysis might dominate any influence from past shows.

H2 tests for the effect of social in-game influences by looking at the effect of the

Table 6.3: Estimation Results

	OLS (reference model)		**Ordered Probit Model 2**		**OLS Model 3 (inc. init. 24 weeks)**		**OLS Model 4 (inc. menu char.)**		**OLS Model 5 (deviations. in cook-evaluator char.)**	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
cooking order										
second	0.276***	0.084	0.226***	0.066	0.235***	0.080	0.273***	0.088	0.280***	0.084
third	0.260***	0.092	0.223***	0.072	0.240***	0.089	0.256***	0.095	0.276***	0.093
fourth	0.467***	0.092	0.386***	0.073	0.437***	0.085	0.429***	0.096	0.476***	0.092
fifth	0.588***	0.103	0.487***	0.080	0.591***	0.093	0.569***	0.107	0.599***	0.104
evaluator already cooked	-0.318***	0.054	-0.245***	0.042	-0.307***	0.051	-0.300***	0.056	-0.324***	0.054
# of ingredients	0.008***	0.002	0.006***	0.002	0.008***	0.002	0.022**	0.009	0.008***	0.002
# of ingredients2/100							-0.011	0.007		
level							-0.137	0.116		
price							0.131	0.110		
av. evaluation level (previous 24 weeks)	0.117	0.265	0.053	0.209	-0.034	0.255	0.116	0.279	0.149	0.261
av. share viewers (previous 24 weeks)	0.200***	0.071	0.168***	0.056	0.249***	0.066	0.196***	0.072	0.190***	0.069
population (city of venue)	0.039	0.032	0.033	0.025	0.017	0.030	0.033	0.033	0.036	0.032
foreign (city of venue)	-0.149	0.265	-0.096	0.198	0.037	0.242	-0.133	0.260	-0.162	0.263
time	0.043	0.726	0.145	0.567	0.712	0.654	0.027	0.718	-0.034	0.706
time2/1000	0.103	0.281	0.037	0.219	-0.166	0.255	0.102	0.280	0.138	0.274
first 24 weeks (indicator)					2.293	1.575				

Note. Displayed are the non-standardized coefficients and standard errors; *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$; robust standard errors (clustered by game day).

position of a contestant. As in previous studies, we find that performing later in the show leads to a significant increase in the evaluation level. A contestant who performs on Friday (OLS reference - "cooking order (fifth)") can expect to receive 0.588 more points than a contestant who performs on Monday. Considering that the maximum point level is 10, this is a substantial advantage. When discussing the theoretical background for H3, we provided a possible explanation for this behavior, direction-of-comparison effects. In the context of "The Perfect Dinner," the existence of this effect implies that contestants performing later have the advantage of being able to provide some sort of unique experience in contrast to previous contestants[10].

H3 relates to the impact of having already cooked on voting behavior by overestimating ones' own performance. The effect is significant and negative, meaning that a contestant who has already cooked will evaluate a cook 0.318 points worse on average than an evaluator who has not yet cooked (OLS reference – "Evaluator already cooked"). This outcome is in line with results from the literature which show a bias towards ones' own performance, especially after completing difficult tasks. Since we also account for the direction-of-comparison effect, it is remarkable that having already performed produces such a strong effect. Combining the two effects leads to an overall expected positive effect for the person to perform last; everyone else has already cooked and the contestant receives 1.08 points more in total than the first contestant. H4 adresses the question of whether the level of sophistication, measured by the number of ingredients, price level and difficulty plays an important role. In the reference specification, the estimated coefficient for "ingredients" is 0.008 and is significant at the 1% level. Thus, on average, using an additional ingredient leads to 0.008 more points for the cook. In a richer specification (Model 4, Table 6.3) we add additional objective characteristics of the dinner, namely its monetary cost and its level of difficulty and the squared number of ingredients. For none of these additional variables the estimated coefficient is significant at the 10% level. Despite of this, the richer specification still provides some indication for a nonlinear effect of the number of ingredients. The p-value (0.117) for the test on the quadratic term just marginally exceeds the threshold of 0.1 and, more important, falls short of it (p-value: 0.083) if the clearly insignificant variables "price" and "level" are excluded. In the latter specification the optimal number of ingredients is about 96. This is in line with the argument that the marginal quality benefit of additional ingredients decreases if a rich set is already used and might even become

[10]The last cook receives a "bonus" of 4* 0.588 via direction-comparison-effects compared to the first cook (Table 6.3, OLS (reference), "cooking order (fifth)"), since each evaluator will give him these 0.588 extra points. Since he is last in the cooking order, 4*0.318 must be subtracted since every other cook that evaluated the last cook has already cooked (Table 6.3, OLS (reference), "evaluator already cooked"). The overall effect is 1.08.

negative since a high quality meal depends on the correct combination of ingredients, not the bare number. What these results clearly show is that a certain level of objective sophistication, measured by the number of ingredients, is appreciated by the evaluators and rewarded.

6.5.2 Individual Characteristics and Dissimilarity

In table 6.4 we report the results for a range of individual characteristics for the cook and evaluator respectively. The only variable that is significant in all estimations is "blonde" for the evaluators. This implies that if an evaluator is "blonde", cooks can on average expect a higher rating than from non-blonde contestants. Furthermore, "age" is significant for evaluators and blonde for cooks when we account for deviations in individual characteristics (Model 5). Yet, in general, neither the cook's nor the evaluator's individual characteristics seem to play a significant role, what is warranted by the test on the joint significance of both groups of variables. However, the result for the interplay of cook's and evaluator's characteristics is a very different one. In all specifications that include "dissimilar" as only variable capturing the interplay of personal characteristics, the estimated coefficient is negative and significant at the 10 percent level. This indicates that socioeconomic proximity leads to more favorable evaluations, which is in line with Hypothesis 6. However, examining the role of similarity in socioeconomic characteristics in more detail yields a more complex picture. In the specification Model 5, we remove "female", "immigrant", "age", and "blonde" from the aggregate measure and include these variables individually as squared differences between cook and evaluator. There, the aggregate effect of residual dissimilarity becomes much smaller (point estimate -0.137 compared to -0.563 in the reference specification) and statistically insignificant, giving rise to the conclusion that the characteristics (occupation, education) that remain in "dissimilar" are of minor importance for biased evaluations in favor of more (resp. less) similar cooks. Moreover, the coefficients of the individually considered characteristics exhibit heterogeneity in the sign. This points to the fact that it is specific to a particular characteristic whether similarity between cook and evaluator leads to more or less favorable evaluations. For example, being of different age and not sharing a migration status leads to more negative evaluation, where the former effect is highly significant and the latter is still significant at the 10 percent level. One may interpret these results as discrimination against cooks from a different age class or a different ethnic background. Yet, the result is equally well explained by preferences that systematically vary with age and migration status. In contrast, for gender and hair color, the estimated coefficients indicate that dissimilarity with respect to these characteristics leads to more favorable evaluations. This provides a strong indication that it is not dissimilarly per se that makes evaluators more critical about cooks

Table 6.4: Individual Characteristics

	OLS (reference)		**Ordered Probit Model 2**		**OLS Model 3 (inc. init. 24 weeks)**		**OLS Model 4 (inc. ingrediences squared)**		**OLS Model 5 (deviations. in cook-evaluator char.)**	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
cooks' characteristics										
female	-0.104	0.073	-0.091	0.057	-0.083	0.067	-0.105	0.076	-0.089	0.072
immigrant	-0.117	0.132	-0.087	0.101	-0.144	0.117	-0.197	0.133	0.038	0.161
age	-0.001	0.003	-0.001	0.002	-0.001	0.003	0.000	0.003	0.001	0.003
student	-0.069	0.197	-0.040	0.151	-0.058	0.185	-0.072	0.202	-0.071	0.194
civil servant	0.248	0.191	0.195	0.154	0.223	0.194	0.186	0.188	0.167	0.188
artist	-0.075	0.173	-0.061	0.133	-0.097	0.160	-0.097	0.178	-0.122	0.170
entrepreneur	0.137	0.148	0.112	0.116	0.151	0.122	0.096	0.155	0.102	0.143
pensioner	0.241	0.486	0.188	0.389	0.423	0.447	0.344	0.561	0.032	0.462
employee	0.021	0.140	0.020	0.110	0.031	0.116	-0.031	0.148	0.008	0.137
academic	0.050	0.121	0.039	0.096	-0.035	0.123	0.057	0.123	0.011	0.124
trainee	-0.075	0.332	-0.078	0.254	-0.055	0.309	0.128	0.356	-0.251	0.321
pupil	0.662	0.548	0.517	0.454	0.656	0.511	0.654	0.567	0.526	0.530
blond	-0.092	0.066	-0.074	0.052	-0.091	0.064	-0.136**	0.068	-0.118*	0.067
evaluators' characteristics										
female	0.038	0.048	0.034	0.038	0.051	0.046	0.033	0.046	0.054	0.047
immigrant	0.035	0.104	0.034	0.082	0.041	0.103	0.055	0.107	0.188	0.138
age	0.005	0.003	0.004	0.002	0.002	0.003	0.005	0.003	0.007**	0.003
student	0.184	0.174	0.123	0.138	0.089	0.155	0.084	0.184	0.183	0.174
civil servant	0.194	0.189	0.147	0.154	0.119	0.177	0.131	0.195	0.114	0.193
artist	0.270	0.173	0.211	0.138	0.232	0.157	0.207	0.179	0.230	0.173
entrepreneur	0.095	0.147	0.057	0.119	0.039	0.130	0.070	0.156	0.061	0.143
pensioner	-0.015	0.277	-0.015	0.217	0.055	0.261	0.086	0.255	-0.202	0.280
employee	0.052	0.139	0.032	0.112	-0.008	0.118	0.006	0.149	0.041	0.134
academic	0.133	0.111	0.098	0.089	0.095	0.103	0.116	0.118	0.095	0.114
trainee	-0.044	0.384	-0.047	0.291	-0.135	0.351	-0.055	0.383	-0.221	0.397
pupil	0.442	0.376	0.338	0.291	0.348	0.359	0.400	0.380	0.316	0.366
blond	0.126**	0.057	0.100**	0.044	0.095*	0.054	0.128**	0.058	0.102*	0.057
dissimilarity										
overall dissimilarity (mahalanobis dist.)	-0.563*	0.292	-0.422*	0.228	-0.524*	0.274	-0.565*	0.299	-0.137	0.242
female (squared diff.)									0.053	0.037
immigrant (squared diff.)									-0.264*	0.137
age (squared diff.)									-0.343***	0.080
blond (squared diff.)									0.078*	0.043

Note. Displayed are the non-standardized coefficients and standard errors; $*p < 0.1$; $**p < 0.05$; $***p < 0.01$; robust standard errors (clustered by game day).

and their performances. With respect to gender and hair color, the results are less easily explained by preference heterogeneity with respect to what is regarded as a high quality dinner and seem to point at discrimination against the evaluator's own sex and own hair color. In quantitative terms, if an evaluator is blonde, but the cook is non-blonde, the evaluator will give a 0.078 higher rating than a non-blonde evaluator. This general pattern of results is confirmed by table 6.5 where we report results of excluding only one – unlike specification Model 5 where four variables are jointly excluded – variable from the "dissimilarity" aggregate measure: Excluding female or blonde increases the level of significance (p-value) of "dissimilarity". In contrast, excluding migrant or age decreases it, rendering it insignificant. This confirms that the negative effect of overall dissimilarity found in the specification of reference is mainly due to similarity in age and migration status while dissimilarity with respect to gender and hair color acts in the opposite direction. Moreover, all excluded variables are individually significant at the 5% or 10% level, indication that all dissimilarity in all four dimensions matter for how favorable the dinners are evaluated.

Table 6.5: Testing for certain dimensions of dissimilarity

	squared difference		**(residual) overall dissimilarity**	
Excluded from overall dissimilarity	**Estimated Coef.**	**p-Value**	**Estimated Coef.**	**p-Value**
none			-0.563	0.055
female	0.069	0.062	-0.699	0.012
migrant	-0.273	0.046	-0.285	0.356
age	-0.354	0.000	-0.069	0.778
blond	0.091	0.038	-0.681	0.016

In Table 6.5 we report results of excluding only one variable from the "dissimilarity" aggregate measure: Excluding female or blonde increases the significance of "dissimilarity". In contrast, excluding migrant or age decreases it, rendering it insignificant. All excluded variables are significant by themselves at the 5% or 10% level. The results we present in Table 6.5 differ from the results of the "OLS Model 5" estimation (Table 6.4), since we excluded all variables at the same time in the estimation. In Table 6.5 only one of the variables was excluded at a time. For example, when looking at the results for the variable "migrant" which implies that this variable was excluded, "female", "age", and "blonde" are still part of "overall dissimilarity". Therefore, "migrant" and "age" are essential to the significance of the aggregate measure, as "dissimilarity" becomes insignificant without either one of them. If evaluator and cook are migrant and non-migrant, the cook will receive a worse rating than if both were non-migrants or both migrants. Furthermore, the larger the age difference between cook and evaluator, the fewer points will be received by the cook.

6.5.3 Discussion

We separated our analysis of the effect of social factors on the voting behavior of participants in the TV show "The Perfect Dinner" into the following categories: Monetary incentives, reputation, social in-game influences, objective quality, and personal traits. The data did not allow us to present any results concerning the monetary incentives since the monetary prize has remained the same throughout the entire period of investigation. Our analysis showed that the impact of reputation measured by the voting behavior in previous shows did not have any significant influence on voting behavior. The most significant difference in our approach, compared to previous analyses of this TV show, was the introduction of a measure for personal traits and objective quality or sophistication. Thus, the objective sophistication and personal traits seem to dominate any potential reputational effect.

We measured social in-game influences via the following variables: the order of cooking and whether a contestant has already performed. Both variables had a significant effect on voting behavior. Our interpretation of the order of cooking effect related to the literature on direction-of-comparison effects. Contestants that perform later are able to exploit their informational advantage in an overall beneficial fashion. However, the advantage of performing later comes at a cost. If an evaluator has already performed, his evaluations tend to be more critical, which is in line with the overestimation effect described in the literature once a difficult task has been performed. Overall, the final contestant who performs, while having the largest gain from direction-of-comparison effects, also faces the most critical audience.

We investigated the effect of objective sophistication by considering the impact of the price and difficulty level, and the number of ingredients. The number of ingredients plays an important role, as more ingredients imply a higher rating by contestants. However, when excluding price and difficulty and including a squared measure of ingredients, we found a quadratic relationship, with a maximum reached at 96 ingredients. Since the relationship disappears when including price and difficulty, our overall interpretation of this result is that objective sophistication does matter to some degree, as more ingredients usually imply a more difficult menu.

Finally, we considered the effect of individual characteristics. As a first step, we included an aggregate measure of "dissimilarity", which had a significant negative effect on voting behavior. As a second step we took a closer look at the individual characteristics part of the aggregate measure, including them as squared cook-evaluator differences. The difference evaluators "immigrant", "blonde", and "age" were individually significant. Excluding them from the aggregate measure rendered it insignificant. When excluding certain individual characteristics one by one from the aggregate measure, we found that all were significant by themselves. Excluding "age" and "migrant" individually rendered the aggregate measure insignificant, implying that these characteristics play a pivotal role in voting behavior.

"The Perfect Dinner" certainly represents a special case in that contestants are evaluators and subjects of evaluation at the same time. In most settings, these tasks are performed separately. Therefore, one should be cautious in drawing general behavioral conclusions from these results. However, for similar settings, our study can serve as an indication concerning the relative strengths of the behavioral effects.. Furthermore, we showed that when accounting for effects other than rank order as in Haigner et al. (2010), the rank order effects still have a significant influence. Factors such as being dissimilar to another person, having already performed, and the objective sophistication also need to be taken into account. Concerning external validity, our results can serve as an indicator for factors influencing evaluation behavior when employees evaluate how well they work together. A number of companies require their employees to evaluate their co-workers with whom they have worked on projects. These evaluations often have a direct effect on promotions and sometimes bonuses. Since the task that is evaluated can also be considered as a complex one, like the cooking and evening entertainment in "The Perfect Dinner", our results can certainly serve as an indication of factors that influence evaluation behavior. Also, evaluating co-workers which might aim for the same promotion since they work in a similar area can have a direct effect on the probability of an evaluator to receive that promotion himself, similar to the "The Perfect Dinner" setting. Even though the potential prize (promotions, bonuses) is less tangible than the prize money the winner receives in "The Perfect Dinner", evaluators still know that these evaluations are not without consequences. Thus, investigating behavioral effects in employee evaluations can serve as an external validation of our results.

6.6 Conclusion

In this paper we analyzed whether factors such as reputation, social pressure, and personal traits play a role in the voting behavior of contestants in the German version of the TV format, "Come Dine With Me." In the show, contestants must prepare a dinner for each other during the course of a week. Each contestant evaluates the dinners prepared by the co-contestants, and thus, each contestant is also an evaluator. The individual evaluations remain concealed until the show is broadcast approximately two months later. Therefore, disregarding any social or reciprocal preferences, contestants have an incentive to evaluate each other's performance negatively in order to increase their chances of winning with no risk of immediate detection. In order to investigate the impact of social pressure and reputational factors, we estimated a number of regression models that explain the evaluation a cook receives from an evaluator, based on a dataset including shows from the years

2006-2011. We separated our analysis into the following categories: Monetary incentives, reputation, social in-game influences, objective quality or sophistication, and personal traits. Since the prize has remained the same throughout the years, the data did not allow us to present any results concerning the influence of the monetary dimension. We measured the impact of reputation by voting behavior observed in previous shows. This had no significant influence on voting behavior once we account for the impact of the objective sophistication of a dinner and personal traits. Therefore, reputational factors as measured by past voting behavior does not seem to play an important role in this setting.

We analyzed the impact of social in-game influences by looking at the order in which contestants cooked and whether a contestant had already prepared a dinner prior to evaluating a co-contestant. Both of these factors have significant effects on voting behavior. The later a contestant performs, the more points he receives on average. One potential explanation for this stems from the direction-of-comparison effect, which leads to a higher evaluation if a later contestant can exploit information concerning the group's expectations by providing a unique positive experience in comparison to previous contestants. If a person has already cooked prior to evaluating another contestant, we find that the evaluator is more critical of the other contestant's performance. One potential explanation is that a contestant who has already cooked attaches a higher weight to his own performance once it has been carried out. This has been shown to be a relevant influence in the literature, usually termed the "overestimations" effect[11]. Another explanation might be that a contestant that has performed is now free to be more critical of the performance of others since he no longer has to fear being evaluated. However, this effect should play no role because the evaluations remain concealed until the show is broadcast. Nevertheless, this effect may still play a role since we have shown that a variety of social components have an impact on voting behavior despite the fact that the evaluations remain concealed.

The objective sophistication, measured by the number of ingredients of a dinner, has a significant effect on voting behavior. The higher the sophistication, the higher the evaluation received by a contestant. This effect has not been accounted for by previous studies of the TV show "The Perfect Dinner."

Finally, we considered the effect of personal traits. An aggregate measure of dissimilarity based on a transformed Mahalanobis distance between the contestants' socioeconomic characteristics had a negative statistically significant influence on voting behavior. Therefore, we concluded that dissimilarity has an important impact on voting behavior. We also tested which of the personal traits plays the most important role. The traits "migration" and "age" turned out to be the most significant

[11] See for example Moore and Healy (2008).

drivers of the aggregate measure, as excluding them rendered the aggregate measure insignificant.

Concerning external validation our results can serve as an indicator for behavior of employees when evaluating co-workers. These evaluations usually have monetary consequences, although not has direct as the prize money in “The Perfect Dinner”, the task evaluated is a complex one and evaluations are usually carried out anonymously. We leave such a test of external validity to future research.

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